THE UNIVERSITY OF ALBERTA

A COMPARISON OF MAXIMAL OXYGEN CONSUMPTION VALUES AS DETERMINED BY PREDICTED AND ACTUAL TECHNIQUES

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF ARTS

FACULTY OF PHYSICAL EDUCATION

BY

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EDMONTON, Alberta

August, 1964

APPROVAL SHEET

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "A Comparison of Maximal Oxygen Consumption Values as Determined by Predicted and Actual Techniques", submitted by Robert Gerald Glassford in partial fulfilment of the requirements for the Degree of Master of Arts.

ABSTRACT

The study was designed to permit a comparison of the values obtained on four maximal oxygen consumption tests: the Mitchell, Sproule and Chapman Maximal Oxygen Intake Test, the Taylor, Buskirk and Henschel Treadmill test of Maximal Oxygen Consumption, the modified Astrand Bicycle Ergometer test of Maximal Oxygen Uptake and the modified Astrand-Ryhming Nomogram for the Prediction of Maximal Oxygen Uptake. In addition, an attempt was made to determine the degree of relationship between the predictive-type maximal oxygen consumption test, the determined measures of maximal oxygen consumption as yielded by both of the treadmill tests and the bicycle ergometer test and a test of physical fitness. The Johnson, Brouha and Darling test of Physical Fitness was used to determine a fitness score.

A second aspect of the study was an attempt to examine changes in oxygen uptake values on the various tests incurred by additional work after a maximal value had been arrived at on the basis of the criteria established in the test outline.

The experimental group was composed of 24 healthy, physically active male students and staff members of the University of Alberta and soldiers from Griesbach Barracks, Edmonton, Alberta. The age range was 17 to 33 years. The testing sequence was based on a permutation design except for the physical fitness test which was administered on the initial visit.

A Godart Capnograph carbon dioxide analyzer and a Beckman #E-2 oxygen analyzer were used for the gas analysis and their accuracy was validated by the Scholander method.

The mean maximal oxygen consumption values obtained on the Mitchell et al. test, Taylor et al. test and the modified Astrand-Ryhming Nomogram test were found to be significantly larger than the mean obtained on the modified Astrand Bicycle Ergometer test ($p = .05$).

The values (expressed as liters of oxygen consumed per minute) obtained on the modified Astrand-Ryhming nomogram correlated at 0.80 with the physical fitness test, 0.78 with the Mitchell et al. test, 0.72 with the Taylor, Buskirk

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and Henschel test and 0.65 with the modified Astrand Bicycle Ergometer test. Correlations after body weight was partialled out were of the same magnitude.

Of 22 subjects who performed extra worklevels on the Mitchell et al. test after achieving a criterion-designated maximal oxygen uptake, 15 developed a significantly higher value ($p = .01$). Seven subjects participated in this phase of the study on the Taylor et al. test. Three of the seven developed a significantly higher maximal oxygen consumption value ($p = .05$). None of the 15 subjects who did extra work on the modified Astrand Bicycle Ergometer test was able to elicit a higher maximal oxygen uptake value.

Within the limitations of the study it was concluded that:

1. The treadmill tests and the predictive-type test yielded higher maximal oxygen consumption values than did the modified Astrand Bicycle Ergometer test.

2. The correlation coefficients which resulted from a comparison of the Astrand-Ryhming Nomogram test with the other four tests were not significantly different from the correlations that existed between the maximal tests of oxygen consumption and the fitness score.

3. The Astrand-Ryhming test produced a significantly larger variance than did any of the three direct tests of maximal oxygen consumption.

4. The present criteria used for the establishment of a maximal oxygen consumption value on the two treadmill tests studied do not necessarily provide a maximal estimation of this ability for all subjects.

ACKNOWLEDGEMENT

"In the beginning . . . there was light" (Genesis 1:3). The author is most appreciative of the assistance, guidance, constructive criticisms and encouragement given by the members of his committee, Dr. R. B. J. Macnab (Chairman), Dr. M. L. Howell, and Dr. B. J. Sproule. Theirs was certainly the "light" which made the completion of this thesis possible.

To my wife, Alice, whose understanding, patience and unselfish assistance enabled the author to undertake this task, my eternal love.

For the comaraderie, the enlightening and lively discussions, the lighthearted criticisms and unstinting assistance given by Gerrie Baycroft and Tony Sedgwick throughout the study - a hand of friendship through the years.

The author is grateful to the "Men of the Micro-Scholanders", Phil Barril and Rene Roscher, who gave valuable technical assistance in a time of need.

A special acknowledgement is extended to Captain Basil Seaton for his assistance at the outset of this study.

Finally, to the subjects who suffered at my hands and yet never failed to return for the next appointment I can only say that without you the study would have been impossible and that your participation was sincerely appreciated.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

It is generally agreed by exercise physiologists that the ability to perform hard physical work in a temperate environment is related to the maximal capacity of the cardiovascular-respiratory system to take up, transport and give off oxygen to active tissues and for these tissues to use the oxygen (7, 42, 43, 64, 75). Many methods for assessing this particular capacity of an individual have been developed and these developments have been recorded in the literature (10, 56, 72, 75, 82). This particular physiological phenomenon is most frequently referred to as the maximal oxygen intake (or aerobic capacity) and according to many sources is one of the most objective measures currently available to exercise physiologists, physical educators, and others for gaining insight into the physical fitness of an individual as reflected by the cardiovascular-respiratory system (12, 49, 56, 58, 80).

In a recent study, Astrand and Saltin (12) obtained a number of values of maximal oxygen consumption by subjecting the same individuals to a range of muscular activities. Among the activities studied were treadmill runs at constant speeds and varying degrees of inclination and bicycle ergometer rides. Reliable, standardized methods for the direct measurement of maximal oxygen consumption exist for both of these exercise devices (10, 56, 75). It is not clear as to whether or not these techniques yield equivalent values of maximal oxygen consumption.

Although aerobic capacity can be determined with a reasonable degree of accuracy, the methods are time-consuming, require moderately complicated and expensive analyzing equipment and demand a high degree of cooperation from the subject. The question then arises: to what extent may conclusions be drawn as to the maximal aerobic capacity of an individual on the basis of tests performed during submaximal work stress? An indirect method of

assessing this capacity has been devised by Astrand and Ryhming (11) which is based on empirical data obtained initially on 112 subjects aged 18 to 30. The technique involves pulse rate response in the steady state to work loads of submaximal intensity on a bicycle ergometer. A nomogram, first published in 1954 (11) and since adjusted (3), is available for predicting a subject's maximal oxygen uptake from a knowledge of a steady state pulse rate and the submaximal work load. Correction factors are also available for various age groups, both male and female.

How well do the values obtained on the Astrand-Ryhming nomogram compare to values obtained by direct measurement? Astrand and Ryhming (11) give the standard deviation of the regression between the measured and the calculated maximal oxygen intake as ± 9.4 per cent for females and 6.7 per cent for males for two-thirds of the respective cases. In a more recent study (80), the average difference between individually estimated and measured values for maximal oxygen intake was determined (the maximal oxygen intake was predicted from the adjusted nomogram). The mean difference for 44 females was -0.036 ± 0.042 liters per minute when the heart rate in steady state averaged 160 beats per minute and -0.109 ± 0.071 liters per minute for 62 male subjects when the steady state heart rate averaged 156 beats per minute. These differences were not evaluated statistically. Other investigators (43, 86) have found statistically significant differences between the predicted and the directly measured maximal oxygen intake.

The Problem

The purpose of this study is to make a direct comparison between the maximal oxygen intake values obtained on three of the more commonly used tests of this capacity as well as a comparison of these values with the "predicted" value of the maximal oxygen intake as determined by the Astrand-Ryhming nomogram. The tests to be employed are: the Mitchell, Sproule, and Chapman

Maximal Oxygen Intake test (56), the Taylor, Buskirk, and Henschel Treadmill test of Maximal Oxygen Consumption (75), the modified Astrand Bicycle Ergometer test of Maximal Oxygen Uptake (5, 10), and the Astrand - Ryhming Nomogram for the Prediction of Maximal Oxygen Uptake from Submaximal Work (3, 11).

In the problem, the null hypothesis asserts that the means of the four tests will be equal. Ho: $U_1 = U_2 = U_3 = U_4$.

The relationships between the four tests of oxygen uptake as well as the Johnson, Brouha and Darling Physical Fitness test will be investigated.

Subsidiary Problem

A secondary problem will be to determine the effect of continued work on the oxygen consumption of a subject after the accepted criteria designating the maximal oxygen consumption has been reached, i.e., two consecutive oxygen intake readings having a difference of no more than 0.053 liters (56), 0.149 liters (75), and 0.080 liters (10).

Limitations of the Study

1. The study is limited to 24 university students, staff members and soldiers stationed at Griesbach Barracks, Edmonton, Alberta.

2. Only the parameters stated in the problem and the subsidiary problem will be considered.

3. The reliabilities of the methods tested and the reliabilities and limitations of the equipment utilized.

4. The statistical procedures used to analyse the data.

5. The magnitude of experimental error by the investigator.

6. The variation in humidity in the laboratory.

Definition of Terms.

Maximal Oxygen Intake. Mitchell, Sproule and Chapman (56:538) state that "... when one subjects a normal individual to progressively increasing work loads, a linear relation between work load and maximal oxygen intake is

found. Ultimately, maximal oxygen intake per unit of time is reached; beyond this point the work load can usually be increased still further but, ordinarily, oxygen intake levels off or declines". Stated more simply, the maximal oxygen intake is a measure of the maximal capacity of the cardiovascular-respiratory system to take up, transport, and give off oxygen to the working tissues and for these tissues to use the oxygen.

Kilopond Meter (kpm). One kilopond meter is the force acting on the mass of one kilogram (kg) at the normal acceleration of gravity.

Steady State. During this state, the oxygen intake is equal to the oxygen expenditure. For the purpose of the predicted maximal oxygen intake, Astrand and Ryhming's criterion of two or more consecutive pulse rate readings separated by one minute intervals that do not differ by more than $\pm$ 5 beats per minute will be used to designate steady state.

Submaximal and Maximal Work. The essential criterion for the distinction of submaximal from maximal work is whether the subject is able to complete the task or is forced to quit from excessive fatigue or exhaustion.

Endurance. Endurance shall be measured by the time, in seconds, that a subject is able to run (up to a maximum of five minutes) on a motor driven treadmill which is set at a speed of 7.0 miles per hour and a grade of 8.6 per cent.

CHAPTER II

REVIEW OF THE LITERATURE

The Maximal Oxygen Intake. The capacity of an individual for doing hard muscular work can be expressed as the "aerobic" capacity or the maximal oxygen intake (2). In a classic study of the physiology of exercise, Hill and Lupton (45) noted that (a) each individual has a maximum level of oxygen intake per minute, (b) that the level varies from one individual to another and (c) that the extra work done above the maximum level of oxygen intake is by means of "anaerobic" metabolism, i.e., the oxygen requirement comprises oxygen intake plus an oxygen debt.

Mitchell *et al*. (56:538) have proffered a definition of this physiological phenomenon that has obvious implications for this study:

> "When one subjects a normal individual to progressively increasing workloads, allowing sufficient time for recovery between each increment of work, a linear relation between workload and oxygen intake is found. Ultimately, maximal oxygen intake per unit of time is reached; beyond this point the workload can usually be increased still further but, ordinarily, oxygen intake levels off or declines".

According to Hettinger and his co-workers (43) the maximal oxygen intake is the best measure of an individual's "physical fitness" but they add the proviso that the definition of "physical fitness" be restricted to the capacity of the individual to perform heavy work. Taylor and Brozek (74) have labelled it as the best available test, on theoretical grounds, of the function of the cardiovascular-respiratory system and believe it to be a relatively constant characteristic of an individual and more indicative of true change in cardiovascular performance than other tests designed for the same purpose.

The following quotations further exemplify past and present opinions about the maximal oxygen intake:

Astrand (7:308):

> "... the individual's capacity for oxygen intake should be decisive in determining his ability to sustain heavy, prolonged work".

Bock *et al*. (15:136):

"The superiority of the athlete lies in his ability to meet the demand for oxygen".

Cumming and Danziger (29:205):

"Probably the best available measure of the maximum working capacity of an individual is the maximal oxygen consumption".

The maximal oxygen intake has been widely used as a cardiovascular - respiratory function test. Knipping (*op. cit.* 20) studied the maximal oxygen intake in conjunction with respiratory disorders and Herbst (*op. cit.* 20) investigated the maximal oxygen consumption of patients with cardiovascular disorders. It has also been studied in a number of experimentally imposed stress conditions, such as semi-starvation by Keys *et al*. (50), experimental malaria by Henschel *et al*. (41), and bed-rest by Taylor *et al*. (76).

Variation in the Maximal Oxygen Intake. As in most other physiological measures, the inter-individual variation of values of the maximal oxygen intake obtained on normal individuals is considerable. The highest noted value was recorded by Robinson *et al*. (64) on an outstanding middle distance runner. This value was 5.35 liters per minute. The lowest value of the maximal oxygen intake noted in a perusal of the literature was a recording of 0.74 liters per minute found in a four year old girl by Astrand (6).

Intra - individual variations have also been noted in some investigations of the maximal oxygen intake. Astrand and Saltin (12) studied various types of muscular activities and the values of maximal oxygen consumption obtained in each instance. The results are summarized in Table I.

TABLE I

COMPARISON BETWEEN MAXIMAL OXYGEN UPTAKE IN CYCLING IN SITTING POSITION AND OTHER TYPES OF MUSCULAR ACTIVITY

TYPE OF WORK	NUMBER	MEAN VO_2 (LITERS)	DIFFERENCE	P
Cycling	6	4.23		
Cycling arms and legs		4.24	0.01	0.5
Cycling	5	4.47		
Running		4.69	0.22	0.05
Cycling	5	4.47		
Running		4.54	0.07	0.5
Cycling	6	4.36		
Skiing		4.48	0.12	0.2
Cycling	5	4.47		
Cycling Supine		3.85	0.62	0.001
Cycling	6	4.36		
Swimming		3.79	0.57	0.01 0.001
Cycling	3	4.66		
Cranking		3.27	1.39	0.001

Source: Astrand, P.-O., and Saltin, B. (12)

It was noted in the paper that running on a treadmill of 1.75 per cent grade evoked a maximal oxygen intake value of 4.54 liters per minute as opposed to a value of 4.49 liters per minute on a horizontal treadmill and 4.70 liters per minute when the grade was increased to 7.9 per cent. In all instances the treadmill speed was held constant.

The authors stated that running uphill tended to reveal a somewhat higher maximal oxygen intake than other muscular exercises of the type investigated in their study but they were unable to elaborate on the physiological reason for this. Taylor and Brozek (74) suggest that more muscle mass is involved in this type of work with a greater resultant demand upon the cardiovascular - respiratory system. It is interesting to note that Astrand and Saltin (12) did not find the same results in skiing which involved the use of the arms and legs.

Newton (58) examined four separate tests which were designed or modified to give values of maximal oxygen consumption. These were: a) the Balke test (with modifications); b) the Cureton "all - out run"; c) a treadmill test with the rate and grade adjusted to the capacity of the individual; d) the bicycle ergometer test with the brake - load adjusted to the capacity of the individual. Seven subjects aged 19 to 70 were tested and while the data was not treated statistically it was noted that the maximal oxygen intake values obtained on the bicycle ergometer were lower in the case of five of the seven subjects than the values they obtained on the Balke test; but higher than the values obtained on the Cureton all - out run. In six of the seven cases the maximal oxygen intake values as determined on the bicycle ergometer test (d) were lower than those values as determined on the treadmill test (c).

In 1962, Binkhorst and van Leuween (14) did a comparative study of three techniques for determining maximal oxygen intake on a bicycle ergometer. A total of four subjects were used. The first method was that outlined by Astrand (6) and described in Chapter III of this paper. The second method involved a continuously increasing load in which the work commenced at zero resistance and continued to exhaustion. In the third technique, the work was started after a period of warm-up and the work level was continuously increased until a pulse rate in a steady state attained a level between 140 to 150 beats per minute. This load was then maintained until exhaustion. No significant differences between the mean values or between the peak values obtained with the three methods were demonstrated. In their discussion, the authors noted that (14:466) "... it appeared that the aerobic capacity can be determined with the bicycle ergometer with continuously increasing the load in a single session".

A study carried out by Hettinger <u>et al</u>. (43) involved 28 subjects be-

tween the ages of 20 and 30 years. The actual maximal oxygen intake was determined by means of a bicycle ergometer test as described by Astrand _et al_. (10) and the predicted maximal oxygen intake was computed according to the modified Astrand-Ryhming nomogram (3) on the basis of the pulse rate in a steady state at 600, 750, 900, and 1050 kpm. The mean predicted maximal oxygen intake was 2.62 liters per minute and this was significantly different (P=0.05) from the measured maximal oxygen intake (2.38 liters per minute). The authors felt that the reason for this difference might, in part, be due to the fact that the Astrand-Ryhming nomogram was computed on the basis of studies of well-trained athletes.

Recently, de Vries and Klafs (32) reported a study in which a variety of submaximal predictive tests of maximal oxygen consumption were compared with an actual maximal oxygen consumption value determined by means of a bicycle ergometer. A total of sixteen subjects were used and the procedure was similar to that of Mitchell, Sproule and Chapman (56). The warm-up was accomplished by administering the Sjostrand test (71). Six submaximal tests were used to predict actual values for maximal oxygen intake. These were the Sjostrand test, a modified Sjostrand test, the Harvard Step test, a Progressive Pulse-Ratio test, the Delta R.Q. test and the Astrand-Ryhming Prediction test. The author found significant correlations (P=.01) between the actual test of maximal oxygen intake and: a) the Sjostrand test expressed in kilopond meters per minute per kilogram of body weight (r=.877), b) Harvard Step test expressed in liters per minute per kilogram of body weight (r=.766), c) Sjostrand test expressed in terms of body surface area (r=.736) and d) Astrand-Ryhming test expressed in liters per minute (r=.736). Since the Astrand-Ryhming test is shorter and uses only one workload, the authors concluded that no advantage was gained in using the Sjostrand test. It was also noted that those tests in which heart rate during a measured

workload is the basis of prediction seem to have a greater predictive value than those using heart rate in the recovery period.

Factors that Influence Maximal Oxygen Intake. The capacity to perform muscular work varies with a number of environmental or mutually dependent individual factors such as age, body size, sex, environmental temperature, training, functional capacities of the circulatory and respiratory systems, ingestion of food, fatigue and emotion. Many of these have been studied in an attempt to explain some of the intra- and inter-individual variability of the maximal oxygen intake.

Astrand (6) has reported high correlations between the maximal oxygen intake and age, body weight, height, and surface area. This accounts for some of the variation of the maximal oxygen intake between individuals, but actually it is only a small amount of it because of the high correlation between age, height, weight, and surface area.

Age and Maximal Oxygen Intake. If the age group is delimited, the inter-individual variation is reduced, as is shown by considering males between the ages of 18 and 35 years in the studies by Robinson et al. (64), Astrand (6), and Robinson (61). The range for this group was 2.56 to 5.35 liters per minute. There seems to be no doubt but what there is an unequivocal decrease in the capacity for oxygen uptake with increasing age (3, 53, 61). With regard to the maximal oxygen intake expressed as milliliters per kilogram of body weight a still greater decrease is obtained. This was pointed up in studies by Astrand (3, 4). Results by Cohn et al. (23) imply that one limiting factor for oxygen transport in heavy exercises for older people might be the diffusing capacity of the lungs.

Sex and Maximal Oxygen Intake. Inter-individual variations are further noted in comparing the maximal oxygen intake of males with those of females (3, 6).

Training and Maximal Oxygen Intake. With respect to intra- and inter-individual variation in maximal oxygen intake values, the effect of training appears to be of some importance. Knehr et al. (51) found a 7 per cent increase in the maximal oxygen intake for 14 men studied over a period of six months of training. In a similar study, Robinson (62) found a 16 per cent increase with prolonged training for middle distance running. Karpovich (49) reported that an untrained man may have a maximal oxygen consumption of 2 liters per minute and a trained athlete may double this amount. Buskirk and Taylor (21) and Dempsey (31) found higher maximal oxygen intakes in individuals undergoing regular physical exercises.

Body Weight and Maximal Oxygen Intake. It has been recognized for many years that the maximal oxygen intake is a function of body size. Many investigators have systematically related observed values of maximal oxygen intake to body weight (61, 64, 88). Buskirk (20), Buskirk and Taylor (21) and Welch et al. (86) have found statistically significant relationships between body weight and maximal oxygen intake. It was shown by Keys et al. (50) that semi-starvation results in a decrease of maximal oxygen intake which is proportional to the loss in body weight until a weight loss of 10 per cent is reached. Somewhere between 10 and 17 per cent loss of weight, the decline of maximal oxygen intake is markedly increased and there is a substantial loss in the capacity for anaerobic work.

Craig Taylor (73) studied the effects of submaximal and maximal work with respect to oxygen consumption and body weight. In submaximal exercise, the correlation between oxygen consumption and body weight in relation with the criterion which was time run in minutes on a treadmill was 0.71 and with weight partialled out this correlation changed signs and dropped to -0.23. In maximal work the oxygen consumption with weight and time run dropped to 0.43 but the oxygen consumption per kilogram of body weight was 0.46. Thus,

in submaximal exercise, oxygen consumption was chiefly a function of body weight and only slightly related to fitness but in maximal work the relationship with weight dropped sharply and the correlation with the fitness criterion increased.

It is important to note that the same load is usually placed on all persons independent of body weight when they are cycling, while in running on a treadmill the work load varies for various subjects due to differences in body weight. This points out the need for recording the maximal oxygen intake in milliliters per kilogram of body weight (7). Buskirk and Taylor (21) state that the ratio of maximal oxygen intake per kilogram of body weight provides a measure of immediately available oxidative energy which can be supplied to move a kilogram of body weight from one point to another.

Warm-up and Maximal Oxygen Intake. There are a number of physiological conditions which affect the maximal oxygen intake. Notable among these is the factor of warm-up. A bout of exercises or "warm-up" has been found to produce an increase in the maximal oxygen intake of approximately five per cent (74). Ten to fifteen minutes of walking at 3.5 miles per hour on a 10 per cent grade was found to be an adequate exercise period for this effect. Mitchell, Sproule, and Chapman (56) have found that after a "warm-up" has been achieved maximal oxygen determinations can be repeated without affecting their reliability. Asmussen and Bøje (1) indicate that the working capacity is greater and the feeling of stress is less if the individual has been previously subjected to a "warm-up".

Previous Experience on the Testing Apparatus and Maximal Oxygen Intake.

It is interesting to note that Knehr *et al*. (51) observed a significant decrease in oxygen consumption with practice on the treadmill. Erickson and others (35) state that oxygen consumption measured the second time a subject has been on the treadmill gives a valid figure which will not be influenced

by an increase in the experience of the individual in walking on the treadmill.

Emotion and Maximal Oxygen Intake: Submaximal Work Pulse Rate. All experimenters who employ submaximal work tests appear to make an unstated assumption that the stress of work overrides any effect of emotion on the behavior of the work pulse rate. Brouha and Heath (17) support this postulation whereas Taylor et al. (77) cite evidence to support the claim that initial contact with a work test can result in significant increases in the submaximal work pulse rate. Astrand and co-workers (9) believe, on the basis of their investigations, that apprehension may have a marked influence on the heart rate and respiratory rate of a subject during rest, but that during exercise the psychic influence on heart rate and respiration is "more or less" abolished.

Direct evidence on the effects of emotion on the maximal pulse rate and maximal oxygen intake is generally lacking in the literature but a recent article by Taylor and others (77) throws some light on this question. A group of seven young men were tested at submaximal and maximal levels for pulse rate and oxygen consumption. Cardiac catheters were used during the testing periods both before and after a period of intensive training and the results would indicate that the maximal pulse rate insensitive to stressful situations.

Environmental Temperature and Maximal Oxygen Intake: Work Pulse Rate.

It was found by Williams and others (87) in a study of three Bantus who were well acclimatized to heat that work in a hot environment would move the pulse rate / work rate curve to the left but that the maximal pulse rate would not be altered. Rowell and his collaborators (op. cit. 77) studied men who were unacclimatized to high temperatures and showed that the same phenomenon existed but that in the unacclimatized men the maximal pulse rate

was reached at a lower level of work and that oxygen intake in liters per minute could be increased as much as 2 liters per minute with no change in the maximal pulse rate. It was further shown that work in 65 degree F. temperature tended to displace the curve to the right of that curve plotted for work done in ambient temperatures of 78 degrees F. Taylor _et al_. (75) found that room temperature was important in standardization of experimental conditions. They recommended a room temperature of 78 ± 4 degrees F. as did Erickson _et al_. (35) and Buskirk _et al_. (21).

Ingestion of Food and Maximal Oxygen Intake: Work Pulse Rate. The effects of meals on the circulation at rest has been extensively studied (54, 75) and it is well known that meals increase the pulse rate and cardiac output. Lundgren (54) has published the effects of a breakfast on the work pulse rate of lumberjacks. At an oxygen consumption of one liter per minute the pulse rate difference was found to be 18 beats per minute. Unpublished results from the Laboratory of Physiological Hygiene (_op_. _cit_. 77:705) showed that at an oxygen intake of 2 liters per minute, a 1000 calorie meal increased the work pulse rate from 132 to 144 beats per minute. The effect had not disappeared completely at the end of one and a half hours. It is interesting to note that a small meal (750 calories) had no demonstrable effect on the maximal oxygen intake (75).

Fatigue and Maximal Oxygen Intake: Work Pulse Rate. Lundgren (54) examined the effects of various degrees of fatigue in relation to the work pulse rate and oxygen consumption. He found that an 8 hour work day had the effect of raising the pulse rate and the oxygen consumption for a fixed amount of work. It was also noted that a walk of 7 kilometers did not cause a shift in the pulse rate / work rate curve but that a walk of 15 kilometers did. The maximal oxygen intake was not studied.

Hemoglobin and Maximal Oxygen Intake. At a given blood flow through a hard-

working group of muscles the oxygen supply will be determined by the oxygen-transporting capacity of the blood, i.e., by the amount of hemoglobin and oxygen saturation. According to Astrand (7), determination of the amount of hemoglobin probably is the best investigation of aerobic capacity at rest. One investigation (6) on healthy individuals indicated a correlation coefficient of 0.97 for the relation between total hemoglobin and maximal oxygen intake.

The Maximal Oxygen Intake Test. When it is desirable to use a maximal (or submaximal test) for a heterogeneous group of subjects which includes the extremes of high and low fitness certain considerations apply:

(a) the intensity and duration of the submaximal exercise cannot exceed the capacities of the poorest subject,

(b) a maximal test, on the other hand, must bring all subjects to a comparable degree of exhaustion.

Two major types of maximal tests have appeared in the literature:

Type I - Work to exhaustion or fatigue with a work load initially set near the subject's limit of capacity (12, 14, 48, 51, 58).

Type II - A graded series of work loads bringing the subject gradually to a point of exhaustion (6, 12, 56, 75).

Taylor (72) stated that the single work load method is inadvisable for a heterogeneous group of subjects because no matter what the intensity and duration, strong subjects tended to reach a steady state and continue for a relatively long period of time before becoming sufficiently fatigued to stop, whereas weak subjects tended to become exhausted very quickly. A distribution of performance scores, obtained on such an experiment displayed a marked positive skewness. On the contrary, such a tendency was avoided in the graded series type of experiment which, with heterogeneous groups of subjects, gave an approximately normal distribution of scores.

The Bicycle Ergometer and the Treadmill as Experimental Devices for Eliciting Maximal Oxygen Consumption. For a test of physical working capacity (the ability to pick up, transport, and give off oxygen to the working tissues) certain conditions are required (82:17):

(a) a large number of muscles must be involved so that the test will not give a conception only of the working capacity of the muscles, i.e., local muscular fatigue;

(b) Different and sufficiently heavy loads must be used to make it possible to estimate the maximum steady state of the subject in question;

(c) It must be possible for most of the subjects to attain steady state during moderate work loads;

(d) The working time must not be excessive.

There is common agreement on the superiority, at least for precise research, of special devices which ensure exact reproducibility of work loads. Of these devices the bicycle ergometer and the motor driven treadmill appear to be the outstanding instruments of choice. Ericksen et al. (35) expressed the opinion that except for cost and portability, the treadmill is preferred to the bicycle ergometer. They cite the main differences as:

(a) "The work load on the treadmill is fixed without any requirement for the subject to keep time".

(b) "Skill and apparatus - training factors are at a minimum on the treadmill - everyone knows how to walk". Dill, Talbott and Edwards (33) have indicated that individual differences in skill in running on a treadmill resulted in measurable differences in mechanical efficiency.

(c) "A larger total energy expenditure is obtainable on the treadmill".

(d) "On the treadmill the work load is automatically adjusted to body size."

The advocates of the bicycle ergometer test counter with some of the following advantages of the bicycle ergometer:

(a) It is a practical apparatus for the laboratory or for field work since it takes up a small area and is easy to transport and to handle.

(b) Work loads can be reproduced as exactly as those on the treadmill.

(c) Oxygen consumption is directly related to the work level and the mechanical efficiency determined on various individuals showed comparatively slight differences (82).

(d) Various determinations, such as blood lactate, maximal oxygen intake, are readily made during work on a bicycle ergometer (9).

(e) Hydrostatic changes in blood distribution may be expected to play a slight role (82).

In areas where bicycles are used by a large fraction of the population the test - retest intra - individual differences in the oxygen requirement for a fixed amount of work was small when body weight was partialled out (6). It is not so clear that this will be so in areas where bicycle riding is not so popular. Furthermore, evidence exists that repeated bouts of work on the bicycle resulted in a substantial change in mechanical efficiency (51:290).

The Mitchell, Sproule, and Chapman Maximal Oxygen Intake Test.

The maximal oxygen intake has been determined in a number of ways as has been noted. However, when a treadmill is used as the exercise device, the work intensity can only be increased by increasing the speed of running, the degree of inclination, or a combination of the two. Mitchell, Sproule, and Chapman (56) have devised a treadmill test that employs a constant speed and a step-wise increase of the work load. A major advantage of this test was that it could be completed in a single session. The test employed by these authors (56) consisted of the following procedures:

(a) The test began with a 10 minute warm-up at 3 miles per hour at a ten per cent grade.

(b) A 10 minute rest followed the warm-up and each subsequent run.

(c) The subjects ran for 2.5 minutes at zero per cent grade and expired air was collected during the last minute of the run in order to determine oxygen intake.

(d) The grade was increased by 2.5 per cent for each subsequent run until the oxygen intake levelled off or the difference between two successive trials did not exceed 0.053 liters per minute. The reliability of a modified version of this test was reported as 0.926 by Coyne (27) on a test - retest basis of 28 subjects.

Taylor, Buskirk and Henschel Treadmill Test of Maximal Oxygen Consumption.

This test (75) began with the subjects in a post - absorptive state. A preliminary walk at 3.5 miles per hour at a 10 per cent grade was followed by a 5 minute rest. Following the rest, subjects ran for 3 minutes at 7 miles per hour on a grade previously selected on the basis of the score the subject received from the Harvard Fitness Test as devised by Johnson et al. (48). Each subsequent run was at a grade 2.5 per cent higher than the previous run and was held on a separate day. If two successive determinations of oxygen intake differed by less than 150 c.c. per minute, it was considered that the maximal oxygen intake had been reached. The test took from 3 to 5 days to administer.

These authors (75) made the following observations:

a) Using a constant speed and increasing the grade was more satisfactory than using a constant grade and varying the speed.

b) Oxygen intake apparently reached a steady state in the 3 minutes allotted.

c) An increase of 2.5 per cent in the grade was accompanied by an increase in oxygen consumption of approximately 300 c.c. per minute.

The reliability of this test (r=0.95) was reported to be constant over a one-year period (75:80). Buskirk and Taylor (21:75) later reported a test-retest correlation of 0.98.

Astrand Bicycle Ergometer Test of Maximal Oxygen Uptake. In 1952, Astrand (6) outlined a bicycle ergometer test designed to determine the maximal oxygen intake. The test was originally carried out on a Krogh bicycle ergometer but since that time von Döbeln (79) has devised an ergometer that is based on a sinus balance system of braking. The gearing and the circumference of the wheel have been so dimensioned that one complete turn of the pedals moves a point on the "rim" 6 meters. Astrand (6, 10, 12) has recommended a pedalling frequency of 50 complete pedal turns per minute. A metronome set at 100 single beats per minute was used to establish this rhythm. With the resistance set at 1 kilogram (1 kilopond) this frequency resulted in 300 kilogram (kilopond) meters of work per minute.

The working intensities for male subjects were 900, 1200, 1500, 1800 and 1950 kpm per minute or higher if the strength of the subject so dictated. No indication of a warm-up period was noted. Successive increases in the work intensity were carried out over a period of several weeks.

This test was modified in 1959 (10) and two work loads per day were combined with the length of the work period set at 5 to 8 minutes and a rest period of 5 minutes permitted between each work level.

During the last two minutes of the work period, gas samples were taken in two separate one minute Douglas bags. The mean value of oxygen consumption obtained in the analysis was used unless the second bag showed a significantly higher value. The criterion for significance was noted to be an increase of 80 milliliters of oxygen consumption per minute (3). Irma

Astrand (4) and Borg et al. (16) both limited the work period at each level to six minutes. Borg and Dahlstrom (16) calculated the maximal oxygen intake in a single session.

The criterion indicating the maximal oxygen uptake was taken to be two successive oxygen uptake values, determined on separate work levels, that differed by 80 milliliters or less.

Borg and Dahlstrom (16) studied the reliability of the Astrand bicycle ergometer test and obtained intra-test correlations of a magnitude ranging up to 0.97 and a test - retest correlation of 0.75. The interim in the test - retest situation was eight months. Linderholm (op. cit. 16) found a reliability on this test of 0.97 on a test - retest basis over a four day interval.

Criteria of Maximal Oxygen Intake. Taylor et al. (75), in their study on exercise, drew attention to the fact that precise criteria do not exist to establish unequivocally the rate of oxygen intake at which the maximum level is attained. The difficulty in establishing the maximal oxygen intake was demonstrated by Wyndham and others (88) who examined the best fitting curves of oxygen intake plotted against work rate. The curves approached their asymptote slowly. Because of this slow approach to the asymptote of the true curve of oxygen intake plotted against work, the authors believe that no simple criterion to define the level of maximal oxygen intake will suffice, such as those suggested by Mitchell et al. (56), Astrand (10), and Taylor et al. (75). Wyndham and his co-authors stated that the latter's criterion amounted to accepting as the maximal the level of oxygen intake just after the curve commenced to depart from the linear. Higher work rates were not studied by Taylor, Buskirk and Henschel (75). Failure to consider the slow approach of oxygen intake to the asymptote could cause an underestimation of the maximal oxygen intake.

Predicted Maximal Oxygen Intake Values from Submaximal Work. Reliable methods for direct measurement of the maximal oxygen intake exist but they are not suitable as routine procedures in mass examinations. A close linear relationship between the heart rate and oxygen consumption is purported to exist under the stress of submaximal work loads (6, 15, 29, 35, 43, 52, 54, 72, 82).

The relation between pulse rate and oxygen consumption or work load was studied statistically by a few investigators. Erickson *et al.* (35) found a correlation coefficient of 0.972 between pulse rate during work on a treadmill and oxygen consumption; Taylor (72) worked with a bicycle ergometer and found a correlation of 0.969 between heart rate and work load.

Lundgren (54) investigated the connection between pulse rate and oxygen consumption, and found a "fairly good" correspondence between the two variables.

Criteria for a Submaximal Test for Maximal Oxygen Intake Prediction.

Astrand (7:324) summarized the criteria which he felt should be met by any submaximal test which was to be used to make predictions of a subject's maximal oxygen intake:

> "If the aim is to examine the physical work capacity of an individual, the examination should be made DURING muscular work. In such a case it is possible to use submaximal work intensity. Great muscular groups should be engaged in the test work. By this means the oxygen transporting systems can be exposed to a stress without causing local muscular fatigue to be a limiting factor. The work must be technically fairly actively constant, and this efficiency should be fairly high. The work load must be carefully determined and be reproducible. Apparatus that satisfy reasonable demands are the treadmill and the bicycle ergometer.
>
> Investigations should be made during a steady state. The work intensity should not be so high as to make "motivation" play a dominant part."

The Nomogram for Prediction of Maximal Oxygen Intake. It was found by Astrand (6) that when subjects underwent muscular activity of such

severity that the demand for oxygen intake was 50 per cent of the individual's maximal oxygen intake, the heart rate after approximately 6 minutes of work for a group of 50 healthy male subjects averaged 128. The corresponding average heart rate for 62 females was 138. When the subjects worked with a heavier load, which demanded an oxygen intake of 70 per cent of their aerobic capacity, the average heart rate was 154 for males and 164 for females (σ = 8 - 9 beats per minute). Based on those values a nomogram was constructed (11) for predicting the maximal oxygen consumption of healthy individuals between ages 18 and 30, by measuring the heart rate and having a knowledge of the work level or the oxygen intake at submaximal levels. The authors stated that best results were obtained when the work level was of such severity that the heart rate during a steady state was between 125 and 170 beats per minute.

These authors (11) presented data showing the error in the method when the maximal oxygen consumption was determined directly and when it was calculated from the nomogram. The comparisons are shown in Table II.

TABLE II

COMPARISON OF MAXIMAL OXYGEN INTAKE AND VALUES FROM THE NOMOGRAM

Sex	Activity	Maximum oxygen intake, liters / minute	
		Determined	Nomogram
Male	Cycling, 900 kpm/min.	4.11	4.07
Male	Cycling, 1200 kpm/min.	4.15	4.17
Female	Cycling, 600 kpm/min.	2.87	3.00
Female	Cycling, 900 kpm/min.	2.91	2.92
Male	Step Test	4.03	4.03
Male	Running, 10 km/hr., 1% grade	4.07	4.05

Source: Astrand and Ryhming (11:220)

More recently, Irma Astrand (3) has published an adjusted nomogram for the prediction of aerobic work capacity. The nomogram was adjusted

for age and the following factors were given to make the required adjustment:

TABLE III

NOMOGRAM CORRECTION FACTORS RECOMMENDED FOR MEN AND WOMEN

Age	Factor for Men	Factor for Women
20	1.06	1.00
30	0.93	0.90
40	0.82	0.82
50	0.74	0.75
60	0.67	0.69
70	0.61	0.64

Source: Astrand (3:53)

Astrand (3:61) strongly emphasized that:

> "... this method of measuring only the submaximal oxygen uptake or workload and heart rate will always be only an aid for a rough prediction of the aerobic work capacity. If one wishes to obtain more exact information, it is necessary to measure the aerobic work capacity directly".

In an attempt to determine the accuracy of the new adjusted nomogram a study was made on 44 female and 62 male subjects (3). The following table was drawn up from the data quoted:

TABLE IV

ACCURACY OF PREDICTION FROM THE NOMOGRAM

Sex	Number	Heart Rate	Average Difference Between Estimated VO_2 and Measured VO_2
Female	42	135 ± 1.2	0.014 ± 0.063 (S. D. = ± 0.376)
		160 ± 1.2	-0.036 ± 0.042 (S. D. = ± 0.253)
Male	42	135 ± 1.8	-0.029 ± 0.090 (S. D. = ± 0.411)
		156 ± 2.3	-0.109 ± 0.071 (S. D. = ± 0.323)

Source: Astrand (3:55)

The mean differences between the estimated maximal oxygen intake and the calculated value were not treated statistically and it is not known if these two values were significantly different.

A previously reported study by Hettinger and others (43) involved a comparison of the measured maximal oxygen intake as determined by the Astrand bicycle ergometer technique (6, 10) and the "predicted" maximal oxygen intake made on the basis of the Astrand-Ryhming nomogram (3) in which corrections were made for age. The mean "predicted" value was significantly higher than the mean of the calculated maximal oxygen intake ($P = 0.05$).

From 1956 to 1959, all Swedish Air Force pilots were examined for physical working capacity at least twice per year (80). The physical working capacity was determined on the basis of the subject's pulse rate response in steady state to stepwise increased submaximal loads on a bicycle ergometer. The Astrand-Ryhming nomogram (11) was used to estimate the individual's maximal oxygen intake. The average maximal oxygen intake was calculated to 3.5 liters per minute on the basis of the nomogram values. It was suggested that for practical purposes in mass testing of healthy men, the physical working capacity be determined from a steady state pulse rate after 6 to 10 minutes of work at a single work load.

Recently Wyndham et al. (88) criticized the use of the nomogram. They found in a study on maximal heart rate and maximal oxygen uptake that the relationship between these two variables was rectilinear only up to a certain heart rate near the maximal. Thereafter, the curve approached a horizontal asymptote in a diagram where heart rate was on the ordinate. They concluded that, when using the nomogram, these results influenced the predicted aerobic capacity so that it would be underestimated by

0.32 ± 0.14 liters per minute. Astrand (3:60) countered with the statement:

> "It is not the premise of the nomogram that the heart rate is a rectilinear function of oxygen uptake throughout the range of values. It was constructed empirically from data on heart rate and oxygen uptake during submaximal work, and maximal oxygen uptake actually measured, in experiments where this oxygen uptake reached a well established level. It was not analysed whether or not the heart rate increased with the oxygen uptake at the upper level".

Astrand also pointed out the fact that the Wyndham *et al*. study was carried out at an altitude of some 5,500 feet. She stated that it was conceivable that the effect of prolonged hypoxia might cause discrepancies between actual and predicted values.

CHAPTER III

METHODS AND PROCEDURE

Twenty-four healthy male subjects were used in this study with the total being comprised of volunteer students and staff members of the University of Alberta as well as soldiers of the Princess Patricia Canadian Light Infantry stationed at Griesbach Barracks, Edmonton, Alberta. The ages of the subjects ranged from 17 to 33, with the mean age being 23.4 years.

The tests were conducted over a period of two to four weeks with a minimum of two and a maximum of seven days between separate tests.

In order to reduce the possible training effect of the series of tests on the obtained mean values of the maximal oxygen intake of the different tests, the testing order was arranged by means of permutations. The permutations or testing sequences were drawn up prior to the commencement of the experimentation, and each permutation was given a number. Subjects and numbers were matched by a chance procedure. The following formula was used to determine the permutation number:

$${}^{n}P_{r} = \text{number of arrangements of four tests taken four at a time}$$

$$= N(N-1)\ .\ .\ .\ (N-r+1) = \frac{N!}{(N-r)!}$$

Where $N = r = 4$

$${}^{N}P_{r} = 4! = 24$$

Physical Conditions of the Testing Situation. As has been noted in the previous chapter, the Maximal oxygen intake can be affected by temperature variation (67, 75) in the testing situation. In this study the laboratory temperature was standardized at 72 $\pm$ 4 degrees F. but the relative humidity was not controlled.

Standardization of the Test Situation. In view of the known effect of the ingestion of food on pulse rate and cardiac output (54, 75) no test was scheduled for a period of one and a half hours following a meal. Subjects were requested not to smoke for thirty minutes prior to the test and although Lundgren (54) indicated that moderate amounts of work prior to a test did not affect the maximal oxygen intake, all subjects were advised not to perform any abnormal or strenuous activities for two hours before their appointment. In all instances, the test schedules for each individual were arranged so that the subject was tested at the same relative time of the day.

Orientation Period. Each subject was brought to the laboratory one to three days prior to the commencement of the actual test for the purpose of orientation. At this time height, weight and age were initially recorded. The testing procedure was explained as carefully as possible and each subject was given a copy of his testing timetable. Since most of the subjects were unfamiliar with the motor-driven treadmill and the bicycle ergometer, they were given ample opportunity to practice on both instruments (35, 51). The subjects were also familiarized with the respiratory apparatus. Following this practice period the subject was permitted a thirty minute rest and this was followed by an exhaustion run on the treadmill conducted in the manner described by Johnson, Brouha and Darling (48).

Respiratory Apparatus. Otis-McKerrow two-way respiration valves of a low-resistance diaphragm type were used (see Figure V). The valve was connected by a 1.5 inch flexible plastic hose to a 150 or 200 liter Douglas bag. A three-way Thomas valve was placed at the junction of the airway leading from the mouthpiece into the Douglas bag. Valves, mouthpiece and connecting tubing were supported by a headgear comfortably fitted to each subject.

Pulse Rate Recordings: Heart rate measurements were made by means of a Sanborn portable electrocardiogram, the leads of which were attached to two chest electrodes and a reference electrode which was placed on the subject's forehead (see Figure VI). Careful attention was given to grounding the electrocardiogram and to preparing the electrodes with Redux (tradename) to ensure better recordings.

Johnson, Brouha, and Darling Test of Physical Fitness for Strenuous Exercise (Harvard Physical Fitness Test). This test was used by Taylor *et al.* (75) to make an estimation of the correct grade which would yield a maximal oxygen intake. The test was performed on a motor-driven treadmill, with a speed range of 2.5-15 miles per hour. Each subject was told exactly what procedures would be followed. These are listed below:

1. The subject warmed up by walking at an 8.6 per cent grade for five minutes at 3.5 miles per hour.
2. A rest period of five minutes in the sitting position was allowed.
3. At a signal, the subject began to run uphill at 7 miles per hour on a grade of 8.6 per cent. If he was not exhausted at the end of the five minutes he was stopped. In all cases, the duration of the run was noted to the nearest second.
4. Recovery time was noted from the cessation of the run and pulse rates were recorded on the electrocardiogram from 1 to 1.5, 2 to 2.5 and 4 to 4.5 minutes of recovery.
5. An arbitrary score of physical fitness was calculated by the formula:

$$\frac{\text{(Seconds the subject ran) X 100}}{\text{2 X sum of three half-minute recovery pulse rates}}$$

6. The score was referred to the following table to establish the appropriate level for the Taylor, Buskirk and Henschel Maximal

Oxygen Consumption test:

TABLE V
HARVARD PHYSICAL FITNESS SCORES

Grade %	Time of run, sec.	Score
5.0	130 - 190	40 - 60
7.5	190 - 300	55 - 80
10.0	240 - 300	80 - 92
12.5	300	95 - 105

Source: Taylor et al. (75).

Taylor, Buskirk and Henschel Maximal Oxygen Consumption Test. In 1955, Taylor et al. (75) described the following treadmill test which they felt gave a value for the maximal oxygen consumption of an individual. The test was performed on a motor driven treadmill (previously described). Each subject was briefed as to the exact procedures to be followed. Procedure:

1. A 10 minute warm-up walk was performed at 3.5 miles per hour on a 10 per cent grade and this was followed by a 5 minute rest.
2. The subject commenced running at 7.0 miles per hour on the grade selected the day before on the basis of the Johnson, Brouha and Darling test and continued to run for a three minute period.
3. At the beginning of the run the breathing valve apparatus was fitted to the subject's mouth by means of a soft rubber mouth-piece, and a nasal clamp was placed over the nostrils. Exhaled air was collected between 1 minute and 45 seconds and 2 minutes and 45 seconds. The oxygen consumption was then determined.
4. On the third visit to the laboratory, the procedure was repeated with the subject running on a grade 2.5 per cent higher than had been employed on the second visit.
5. If the two oxygen consumption values were different by 149 c. c.

per minute or less the working conditions used were considered to have elicited a maximal oxygen intake. If a larger positive difference occurred, a fourth visit to the laboratory was required and the three minute run was carried out on a grade which was increased by 2.5 per cent. This procedure was repeated until two grades were found which resulted in oxygen intake values which met the established criterion.

6. If the subject was unable to complete a level, a gas sample was obtained before the usual time. At times it was necessary to take samples of gas that were less than a full minute in duration. The volume of the sample was then multiplied by a factor to equate it with a full minute sample.
7. Some of the subjects were brought back to the laboratory in spite of the fact that the maximal oxygen intake criterion had been met in order to ascertain any further changes in the oxygen consumption values as obtained at a level 2.5 per cent greater.

Mitchell, Sproule and Chapman Maximal Oxygen Intake Test. This maximal oxygen intake test has been described by Mitchell, Sproule and Chapman (56) and, with some modifications, by Cunningham (30), Coyne (27) and Watson (84). However, these modifications have not been included in this experiment. The test was performed on a motor-driven treadmill. The following procedures were carefully adhered to:

1. A 10 minute warm-up walk was performed at 3 miles per hour on a 10 per cent grade. This warm-up was followed by a 10 minute rest in the sitting position.
2. Before the treadmill was started, the subject was connected to a two-way Otis-McKerrow valve by means of a rubber mouthpiece, and

his nose was completely closed with a nasal clamp.

3. The exercise runs were carried out at a speed of 6.0 miles per hour for 2.5 minutes and expired air was collected in a Douglas bag between 1 minute and 30 seconds and 2 minutes and 30 seconds of the run. The first exercise run was carried out at zero per cent grade.
4. Analysis of the expired air was immediately carried out.
5. After a 10 minute rest period, the work load was increased by raising the grade to 2.5 per cent, the speed being held at 6 miles per hour, and the procedure was repeated until the oxygen intake measured in liters per minute, levelled off or declined. The criterion for deciding whether or not maximal intake had been reached, if the intake did not decline, has been determined by Mitchell _et al_. (56:53) to be a difference of less than 0.054 liters of oxygen per minute between two successive tests.
6. Partial gas samples were obtained during the last portion of the run of any given level if the subject found it impossible to run the required 2.5 minutes.
7. The subject was requested to do the succeeding work level in order to determine any further changes in the oxygen intake values following the establishment of the maximal oxygen intake according to the criterion established by Mitchell _et al_. (56).

Astrand Bicycle Ergometer Test of Maximal Oxygen Uptake (Modified). The bicycle ergometer test was carried out on a Monark Bicycle Ergometer which was designed by von Döbeln (79) and which works on the principle of a weighing device called the sinus balance (see Figure VIII). The procedures adopted were closely patterned after those used and established by Astrand

(4, 5, 10). The only modification to the test was to have the subjects continue the test until the maximal oxygen intake criterion was reached. This was done in a single experimental period.

The pedalling frequency was established by means of an electric metronome (with attached visual stimulator) which was set at exactly 100 single beats per minute. The metronome timing was followed so that 50 complete pedal turns per minute were made. The sinus balance was carefully calibrated before the commencement of the test.

When the work was started, the brake belt was slack and was quickly adjusted to the desired work level by stretching the belt with the aid of a handwheel designed for the purpose. This adjustment could be made in a few seconds but as the wheel and belt warmed up the friction sometimes changed necessitating the occasional readjustment. A check of the load was made at least once a minute.

The height of the saddle was adjusted so that when the subject had the front part of the sole of his foot on the pedal, a slight bend of the knee joint resulted in the extended leg (i.e., the front part of the knee was straight above the tip of the toes). The handlebars were adjusted to the subject's liking.

The same equipment used to obtain heart rate and expired gas samples in the treadmill tests was utilized in this test.

Procedure:

1. The subject was allowed to warm-up for six minutes at the 600 kpm work level which was followed by a five minute rest interval.
2. The work load was increased to 900 kpm and the subject again pedalled at a frequency of 50 revolutions per minute for six minutes. At 4 minutes and 30 seconds of the ride the subject was connected

to an Otis-McKerrow two-way breathing valve by means of a rubber mouth piece and his nose was completely closed with a nasal clamp. An expired gas sample was obtained between the fifth and sixth minute of the ride.

3. A second 5 minute rest period ensued and this was followed by 6 minutes of work at the 1200 kpm level. The above procedure was repeated through the 1500, 1800, 1950 and 2100 kpm levels or portions thereof or until the oxygen intake levelled off or declined. The criterion for deciding whether or not the maximal oxygen intake had been reached was given by I. Astrand (15:49) to be a difference between two successive recordings on separate work levels of less than 0.081 liters of oxygen per minute.
4. If the subject found it impossible to complete a workload, a gas sample was taken at an earlier period. Where possible a full minute of exhaled gas was captured. If this proved impossible a partial minute sample was taken and then equated to a minute volume.
5. The subject was then requested to attempt the next work load in order to ascertain changes that might occur in the oxygen uptake values following the establishment of the maximal oxygen uptake according to Astrand's criterion.

Astrand-Ryhming Nomogram for the Prediction of Maximal Oxygen Uptake From Submaximal Work. For all subjects in this study, the work level was initially set at 900 kpm. Saddle and handle-bar height was adjusted as per previous description and the pedal frequency established at 50 revolutions per minute. Heart rate recordings were made on a Sanborn electrocardiogram during the last twenty seconds of every minute. The subject pedalled at this work level until a steady state was attained (two consecutive heart

rate recordings separated by one minute which differ no more than ± 5 beats). If this steady state was not in the range of 125 to 170 beats per minute the work load was increased to 1200 kpm and the subject continued to ride until a steady state pulse rate was reached.

The steady state pulse rate value was then applied to the Astrand-Ryhming nomogram as adjusted for age (3) in relation to the work load and a maximal oxygen uptake value was estimated.

Method of Determining Oxygen Consumption. The expired air in the Douglas bag was analysed for the percentage of oxygen by drawing a sample of expired air through the exit tubing of the bag via a ¼" vinyl hose into a Beckman #E-2 oxygen analyser. The percentage of carbon dioxide was determined by the same procedure, using a #KK Godart Capnograph infra-red carbon dioxide analyser. Both gas analysers were carefully calibrated prior to use each day and at regular intervals during the testing procedure. The volume of expired air was determined by passing the contents of the bag via a 1.5 inch rubber hose leading from the three-way Thomas valve through an #802 American Meter Company Gasometer at a constant rate of 70 liters per minute with a Collins #p-553, 1/15 horse power centrifugal pump (see Figure I).

Pulmonary ventilation was expressed as liters of air expired per minute, the volume of gas being reduced to the standard temperature and pressure 0°C and 760 mm Hg, dry. The formula used was (26:6, 36:649):

$$\frac{P_B - P_{H_2O}}{760\ (1 + 0.00367\ T)}$$

where P_B = ambient barometric pressure

P_{H_2O} = the vapor tension of water, mm Hg. at the temperature of the gasometer

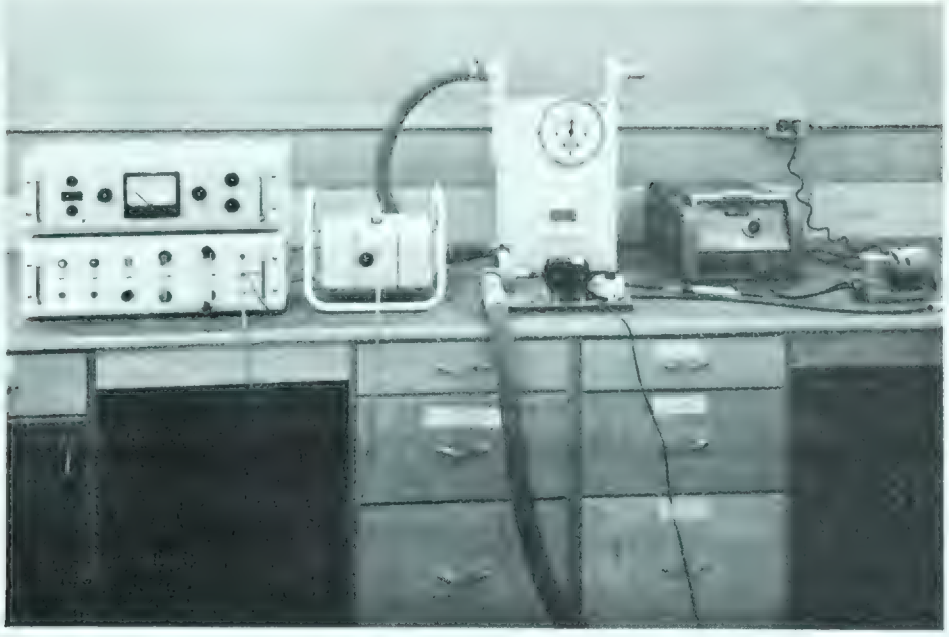


FIGURE I. (left to right).
N.V. Godart CO_2 Analyzer,
Volume meter, Beckman E-2
O_2 Analyzer

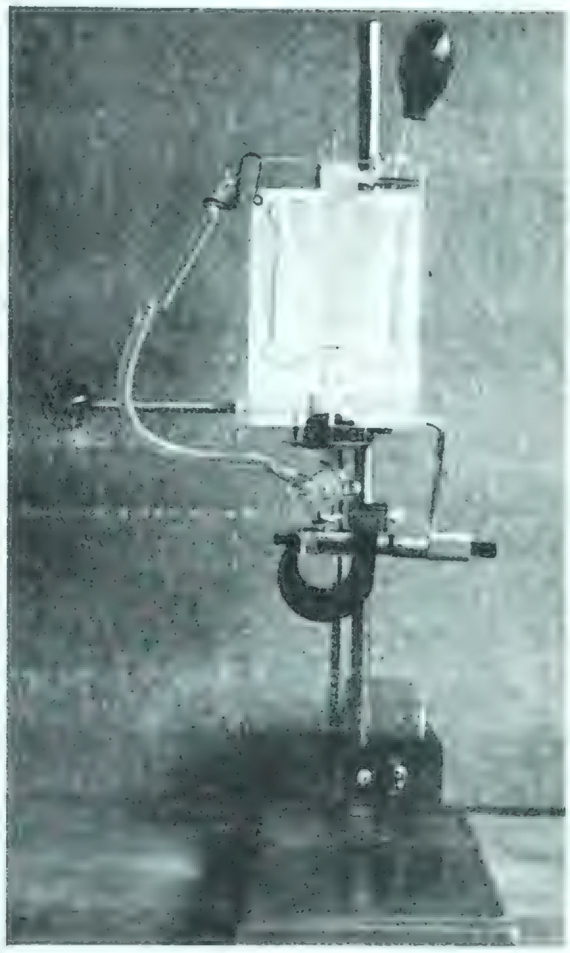


FIGURE II. Micro-Scholander Gas Analysis Instrument

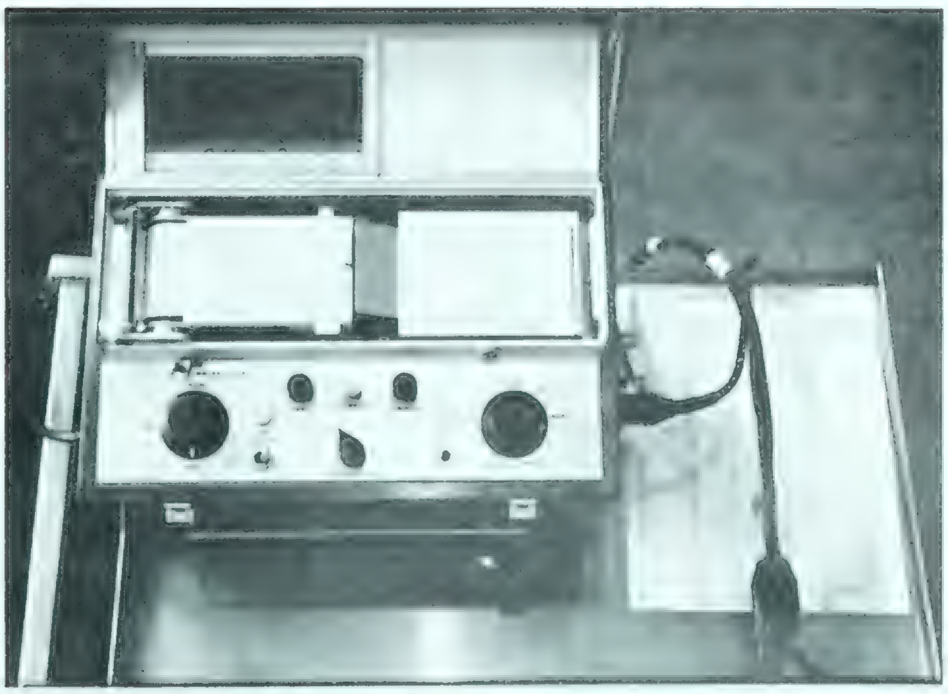


FIGURE III. Sanborn 100 Viso-Electrocardiogram

T = the temperature of the gasometer, °C

For the calculation of oxygen consumption, the change in nitrogen content for correction of expired to inspired volumes, as described by Peters and Van Slyke (60), was employed. The method of calculation is shown below:

1. The following symbols are used for this study:

   a) Fe = % of a particular gas in expired air.

   b) Fi = % of a particular gas in inspired air.

   c) Ve = Volume expired.

   d) Vi = Volume inspired.

   e) ATPS = Atmospheric temperature, pressure, saturated.

   f) STPD = Standard temperature, pressure, dry.

2. The corrected volume of air expired is:

   Ve air STPD = Ve ATPS X the factor for reducing a volume of moist gas to a volume of dry gas at 0° C. and 760 m.m. of mercury.

3. The corrected per cent of oxygen in the expired air is:

   $$Fe\ O_2 = \text{Analyser reading} \times \frac{2.5}{1000}$$

4. The volume of inspired air is:

   $$Vi\ \text{air STPD} = Ve\ \text{air STPD} \times \frac{Fe\ N_2}{Fi\ N_2} \quad (Fi\ N_2 = 79.03)$$

5. The total volume of oxygen inspired (not all consumed) is:

   $$Vi\ O_2 = Vi\ \text{air} \times \frac{Fi\ O_2}{100} \quad (Fi\ O_2 = 20.94)$$

6. The volume of oxygen expired (not consumed) is:

   $$Ve\ O_2 = \frac{Fe\ O_2}{100} \times Ve\ \text{air}$$

7. The amount of oxygen consumed is:

   $$VO_2 = Vi\ O_2 - Ve\ O_2$$

FIGURE IV. (left to right)
Douglas Bags
Breathing Apparatus
Treadmill
Instrument Panel

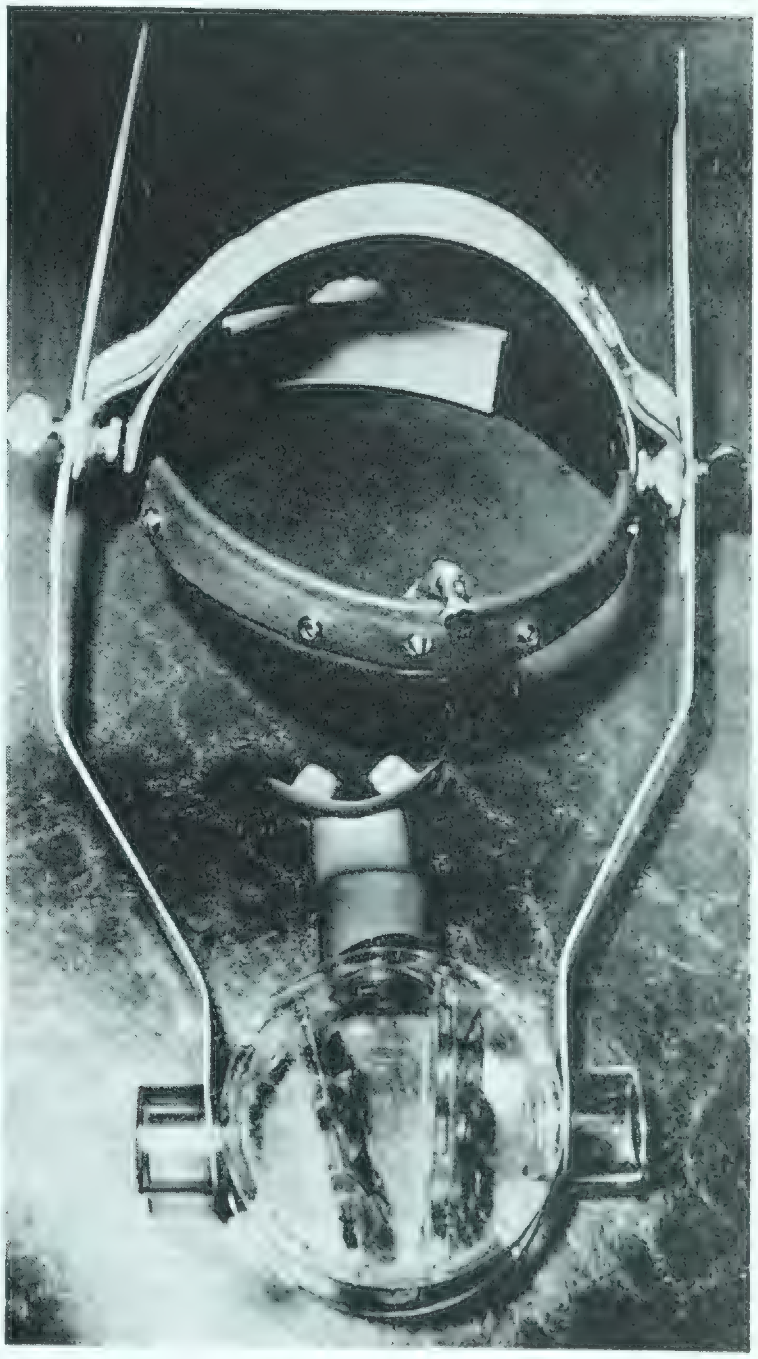


FIGURE V. Modified Otis
McKerrow Valve with
light weight head gear.

FIGURE VI. (left to right)
Sanborn 100 Viso-Electrocardiogram
Subject showing ECG electrode placement
Electric Metronome

Calibration of Instruments and Accuracy of Calibration Gases

Treadmill. The elevations of the treadmills used in this experiment were carefully checked by means of a Miracle Point Mercury Balance Model 10 Inclinometer which registered in degrees. The values were converted to a per cent scale by using a table of tangents (22).

Bicycle Ergometer. The sinus balance was calibrated by means of a set of stainless steel weights, #750 Class S-1 Serial No. 7Y1458 (see Figure IX) in the following manner (8:3):

a) The brake drum was removed and the mark on the pendulum weight was set at "0".

b) A one kilogram weight was attached to the spring as shown in Figure IX. Weights were added or taken from the spring as required to bring the mark on the pendulum to the required scale mark of "1-kp".

c) The process was continued through "2-kp", "3-kp" and so on up to "7-kp".

d) If adjustment was required it was made by means of an adjusting screw which altered the center of gravity of the sinus balance.

American Volume Meter and Collins Centrifugal Pump. The rate of flow through the #802 American Meter Company Gasometer was checked by evacuating a known quantity of gas from a Collins Chain-Compensated Gasometer with a capacity of 120 liters and a factor of 133.2 cc/min.

Calibration Gases for the Beckman E-2 Oxygen Analyzer and Godart Capnograph Carbondioxide Analyzer.

The calibration gases used for calibrating the two instruments were evaluated several times by means of an analytical procedure outlined by Scholander (69) (see Figure II). The tests were carried out by the laboratory technician in the Department of Physiology and the Cardio-Pulmonary laboratory of the University of Alberta hospital.

FIGURE VII. Subject undergoing Astrand-Ryhming Nomogram Test

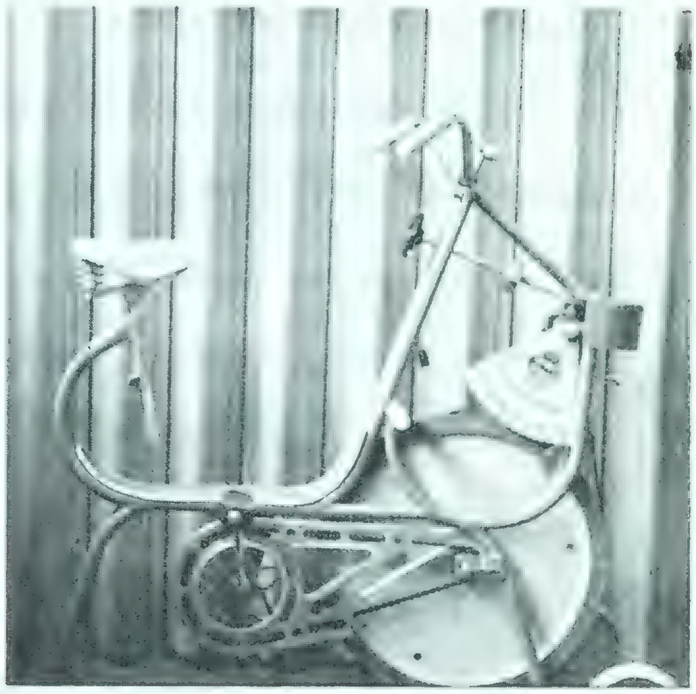


FIGURE VIII. Monark GCI Bycycle Ergometer

FIGURE IX. Calibration technique for Monark Bicycle Ergometer using 3 kilogram weight.

Statistical Treatment. The significance of the difference between means obtained on the four tests of maximal oxygen was tested with an analysis of variance technique for correlated groups with two criteria of classification (39:291). Duncan's New Multiple-Range test was used to determine where, if any, differences between the treatment means occurred. Correlation coefficients between all five tests were determined by means of an I.B.M. - 1620 Electronic Computer program of simple correlations (Number 1620-013) which also provided a mean, variance and standard deviation for each variable. The significance of the difference between two correlation coefficients for correlated samples was calculated by a t-test (83:257). The t ratio of N-2 degrees of freedom (N=sample size) provided a test to determine if the coefficient computed for each set of variables was significantly different from zero (37:152). A t-test for correlated samples was used to determine the significance of the difference between two means obtained on actual values of maximal oxygen consumption and values established by the various test criterion (37:138).

CHAPTER IV

RESULTS AND DISCUSSION

Results

Means and Standard Deviations for the Maximal Oxygen Consumption Tests. The mean values and standard deviations for maximal oxygen consumption obtained on the four tests used in this study are given in Table VI. For the Johnson, Brouha and Darling test of Physical Fitness the mean score was 70.12 ± 17.61.

TABLE VI

MEAN MAXIMAL OXYGEN CONSUMPTION VALUES

Test	Maximal Oxygen Consumption	
	Liters/min.	Ml./kg./min.
Mitchell, Sproule and Chapman	3.752 ± .467*	49.86 ± 5.65
Taylor, Buskirk and Henschel	3.758 ± .327	50.02 ± 4.43
Astrand Bicycle Ergometer	3.485 ± .402	46.31 ± 4.67
Astrand-Ryhming Nomogram	3.714 ± .837	49.30 ± 10.72

* Mean ± Standard Deviation

A test of significance for homogeneity of variance (37:143) showed that the variance of the predictive test was significantly greater ($p = .01$) than other variances. No other significant differences were found. Ferguson (37: 240) states that the assumptions of variance underlying the analysis of variance are only roughly satisfied and that moderate departures from homogeneity should not seriously affect the inferences drawn from the data.

Correlation Coefficients. The relationship between the values of maximal oxygen consumption expressed in liters per minute and in milliliters per kilogram of body weight per minute obtained by the subjects as well as their physical fitness score was calculated by means of a program of simple correlations which was analyzed by an International Business Machine Model 1620 computer. The Pearson Product-moment correlation coefficient formula formed the basis for the program used. Tables VII and VIII contain the correlations thereby determined.

TABLE VII

CORRELATION COEFFICIENTS OBTAINED BETWEEN THE FOUR MAXIMAL OXYGEN CONSUMPTION TESTS AND JOHNSON, BROUHA AND DARLING FITNESS SCORES. (Milliliters per minute per kilogram of body weight).

	MSC	TBH	AA	AP
JBD	.63	.65	.65	.79
MSC		.68	.65	.77
TBH			.74	.62
AA				.63

TABLE VIII

CORRELATION COEFFICIENTS OBTAINED BETWEEN THE FOUR MAXIMAL OXYGEN CONSUMPTION TESTS AND JOHNSON, BROUHA AND DARLING FITNESS SCORES. (Liters per minute).

	MSC	TBH	AA	AP
JBD	.68	.83	.68	.80
MSC		.75	.72	.78
TBH			.82	.72
AA				.65

JBD - Johnson, Brouha and Darling Physical Fitness Test
MSC - Mitchell, Sproule and Chapman Maximal Oxygen Intake Test
TBH - Taylor, Buskirk and Henschel Treadmill Test of Maximal Oxygen Consumption
AA - Modified Astrand Bicycle Ergometer Test of Maximal Oxygen Uptake
AP - Modified Astrand-Ryhming Nomogram for the Prediction of Maximal Oxygen Uptake

All correlations were found to be significantly different from zero beyond the .01 level of confidence (for twenty-four subjects $r \geq .515$ indicated significance at this level).

In view of the fact that there were four tests of maximal oxygen

consumption and one test which gave a physical fitness score it was necessary to decide whether one test was more highly correlated with this fitness index than another. Similarly, three of the maximal oxygen consumption tests were elaborate in design and time consuming to administer whereas the fourth was a short, simple predictive-type test, therefore the question of significantly different correlations between the predicted values, and the actual or obtained values of maximal oxygen uptake was of considerable importance. In order to test the hypothesis that $\rho_{12} = \rho_{13}$ a t-test described in Walker and Lev (83:256) was used. No statistically significant differences were found (p = .05) when the correlation coefficients were tested.

Analysis of Variance of Maximal Oxygen Consumption Values. Tables IX and X indicate the maximal amount of oxygen consumed by the twenty-four subjects on the four tests. It should be noted that these values are the ones obtained according to the various authors' defining criteria of maximal oxygen consumption and are not necessarily indicative of their true capacities of oxygen consumption.

TABLE IX

MAXIMAL OXYGEN INTAKE VALUES EXPRESSED IN LITERS PER MINUTE OBTAINED ON THE FOUR MAXIMAL OXYGEN INTAKE TESTS

	Maximal Oxygen Consumption Tests			
Subject	Mitchell, Sproule and Chapman Test	Taylor, Buskirk and Henschel Test	Astrand Bicycle Ergometer Test	Astrand-Ryhming Nomogram
1.	3.841	4.046	3.598	3.982
2.	4.024	3.850	3.478	4.240
3.	3.743	3.834	3.448	3.074
4.	3.923	3.999	3.498	4.390
5.	2.962	3.218	3.068	2.886
6.	4.278	4.363	3.732	4.754
7.	4.076	4.324	4.346	3.830
8.	4.148	3.805	3.637	5.174

	MSC	TBH	AA	AP
9.	3.670	3.900	3.262	3.720
10.	4.634	3.980	3.861	5.105
11.	3.677	3.693	3.610	4.517
12.	3.699	3.475	3.408	2.735
13.	4.156	4.068	3.912	4.136
14.	3.040	3.336	2.654	2.332
15.	3.424	3.393	3.174	2.895
16.	4.278	3.868	3.717	3.433
17.	3.513	3.972	4.078	4.084
18.	3.219	3.851	3.582	3.380
19.	3.297	3.249	3.106	2.760
20.	2.819	3.245	2.560	2.263
21.	4.036	3.670	3.652	3.350
22.	3.536	3.536	3.469	3.350
23.	3.696	3.510	3.222	4.028
24.	4.347	4.001	3.574	4.712
Mean VO_2	3.752	3.758	3.485	3.714

TABLE X

MAXIMAL OXYGEN INTAKE VALUES EXPRESSED IN MILLILITERS PER KILOGRAM OF BODY WEIGHT OBTAINED ON THE FOUR MAXIMAL OXYGEN INTAKE TESTS

Subject	Maximal Oxygen Consumption Tests			
	Mitchell, Sproule and Chapman Test	Taylor, Buskirk and Henschel Test	Astrand Bicycle Ergometer Test	Astrand-Ryhming Nomogram
1.	54.81	57.73	51.34	56.82
2.	49.77	47.62	43.02	52.44
3.	45.84	46.96	42.23	37.60
4.	45.23	46.11	40.33	50.62
5.	40.06	43.52	41.49	39.03
6.	55.31	56.41	48.25	61.47
7.	52.24	55.42	55.70	49.09
8.	53.63	49.20	47.03	66.90
9.	49.63	52.75	44.12	50.31
10.	60.10	51.61	50.07	66.20
11.	48.25	48.46	47.38	59.28
12.	46.07	43.28	42.45	34.06
13.	53.90	52.76	50.73	53.64
14.	48.22	52.91	42.09	36.99
15.	44.66	44.26	41.40	37.76
16.	51.26	46.34	44.54	41.13
17.	45.56	51.51	52.89	52.96
18.	45.49	54.42	50.62	47.77
19.	50.72	49.98	47.78	42.46
20.	40.09	46.15	36.41	32.19
21.	52.97	48.16	47.93	43.96
22.	45.06	45.06	44.21	42.69
23.	55.06	52.29	48.00	60.00
24.	62.64	57.65	51.50	67.88
Mean VO_2	49.86	50.02	46.31	49.30

In order to test the homogeneity of the means of the four tests an analysis of variance for the two criteria of classification (subjects and tests) was used. The test was designed for testing the significance of the difference between means obtained from correlated groups (39:291). Table XI summarizes the results of the variance analysis for the data expressed in liters per minute and Table XII the variance analysis for the values in which the individual's body weight has been partialled out and the scores expressed in milliliters per minute per kilogram of body weight.

TABLE XI

ANALYSIS OF VARIANCE FOR THE FOUR TESTS
OF MAXIMAL OXYGEN CONSUMPTION
(Liters of oxygen consumed per minute)

Source of Variation	Sum of Squares	df	Mean Square	F
Between Tests	1.204	3	.401	3.427*
Between Subjects	19.231	23	.836	7.145**
Interaction	8.099	69	.117	
Total	28.534	95		

* Statistically significant at the .05 level of confidence.
** Statistically significant at the .01 level of confidence.

TABLE XII

ANALYSIS OF VARIANCE FOR THE FOUR TESTS
OF MAXIMAL OXYGEN CONSUMPTION
(Milliliters of oxygen consumed per minute per kilogram of body weight).

Source of Variation	Sum of Squares	df	Mean Square	F
Between Tests	216.71	3	72.24	3.443*
Between Subjects	2,885.21	23	125.44	5.979**
Interaction	1,447.53	69	20.98	
Total	4,549.45	95		

* Statistically significant at the .05 level of confidence.
** Statistically significant at the .01 level of confidence.

In the case of both the raw score means and the means expressed as milliliters of oxygen consumed per minute per kilogram of body weight, the F-ratio for tests is statistically significant at the .05 level of confidence. Therefore, the null hypothesis with respect to tests or trials is untenable and must be abandoned. The evidence supports the acceptance of the alternative hypothesis that a real difference between the four means does, in fact, exist.

Ordinarily in most two-criteria experiments the primary concern is with one criterion, as here. The F-ratio obtained for subjects is significant beyond the .01 point. It is obvious that some subjects were consistently better than others without regard to trial.

Having determined that the means for the tests were significantly different, further analyses were carried out to ascertain which of the six differences between the four test means were significant and which were not. Duncan's New Multiple-Range test (78:107) indicated that in the case of both sets of scores the modified Astrand Bicycle Ergometer Test of Maximal Oxygen Uptake yielded significantly different means (p = .05) from those obtained on the other three tests. There were no statistically significant differences between any other means. Tables XIII and XIV summarize these results.

TABLE XIII

DUNCAN'S NEW MULTIPLE-RANGE TEST
APPLIED TO THE DIFFERENCES BETWEEN
K = 4 TREATMENT MEANS EXPRESSED IN LITERS PER MINUTE

Means	3.485	3.714	3.752	3.758	Least Significant R
3.485	-	.229*	.267*	.273*	R = .214
3.714		-	.038	.044	R = .207
3.752			-	.006	R = .196

* Statistically significant at the .05 level of confidence.

TABLE XIV

DUNCAN'S NEW MULTIPLE-RANGE TEST
APPLIED TO THE DIFFERENCES BETWEEN
K = 4 TREATMENT MEANS EXPRESSED IN MILLILITERS PER MINUTE
PER KILOGRAM OF BODY WEIGHT

Means	46.31	49.30	49.86	50.02	Least Significant R
46.31		2.99*	3.55*	3.71*	R = 2.861
49.30			0.56	0.72	R = 2.768
49.86				0.16	R = 2.627

*Statistically significant at the .05 level of confidence.

Increased Work and Maximal Oxygen Consumption. A second aspect of this study was to determine the effect of continued physical exertion on the oxygen consumption of a subject after the accepted criteria designating the maximal oxygen consumption had been attained, i.e., two consecutive oxygen uptake readings which demonstrated a steady state, a decline or an increase in oxygen consumed which did not exceed 0.054 liters in the case of the Mitchell, Sproule and Chapman test (56), 0.149 liters for the Taylor, Buskirk and Henschel test (75) or 0.080 liters for the Astrand bicycle test (10). Table XV summarizes those, if any, changes that occurred as a result of the performance of extra work levels.

TABLE XV

MAXIMAL OXYGEN CONSUMPTION VALUES
AS DETERMINED BY TEST CRITERIA AND BY EXHAUSTION
(Liters per Minute)

Test	No. of Subjects	Mean Max. O_2 (Criteria)	Mean Max. O_2 (Exhaustion)	t
Mitchell, Sproule and Chapman	22	3.346 ± .459	3.756 ± .415	4.14 **
Taylor, Buskirk and Henschel	7	3.815 ± .387	3.893 ± .200	2.954 *
Astrand Bicycle Ergometer Test	14	3.152 ± .538	3.152 ± .538	0.00

* Statistically significant at the .05 level of confidence.
** Statistically significant at the .01 level of confidence.

The mean increase in the maximal oxygen consumption values obtained on the Mitchell, Sproule and Chapman test was 0.410 liters. This change was statistically significant at the .01 level of confidence. Of the 22 subjects who participated in this portion of the study, fifteen developed higher oxygen consumption values than the criteria value with which they were credited whereas seven subjects showed a continual levelling off or decline in their oxygen uptake despite the increase in work output.

Oxygen consumption values obtained by the seven subjects who performed extra work on the Taylor, Buskirk and Henschel test showed a mean increase of 0.078 liters. This increase was statistically significant at the .05 level. As a result of the more taxing workloads three of the seven subjects obtained an increase in their oxygen consumption values.

Of the fourteen subjects who participated in this phase of the study by riding extra worklevels on the bicycle ergometer, not one developed a higher value of oxygen consumption. In all cases their maximal level was either maintained or experienced a decline.

Figure X illustrates graphically a typical progression and decline of oxygen consumption values while Figure XI depicts three patterns of oxygen consumption values which resulted from continued exercise after a maximal oxygen consumption value had been reached.

Discussion

Maximal Oxygen Consumption. The physiologist who is concerned with the functioning of the human organism during work may wish to know something about the aerobic capacity of his subject for several reasons. He may want to study oxygen uptake during work in relation to maximal uptake. The physical educator can use the aerobic capacity to study an aspect of physical condition of an athlete and determine the changes resulting from training.

FIGURE X TYPICAL PATTERNS OF OXYGEN CONSUMPTION VALUES FOR THE FOUR TESTS STUDIED (SUBJECT 22)

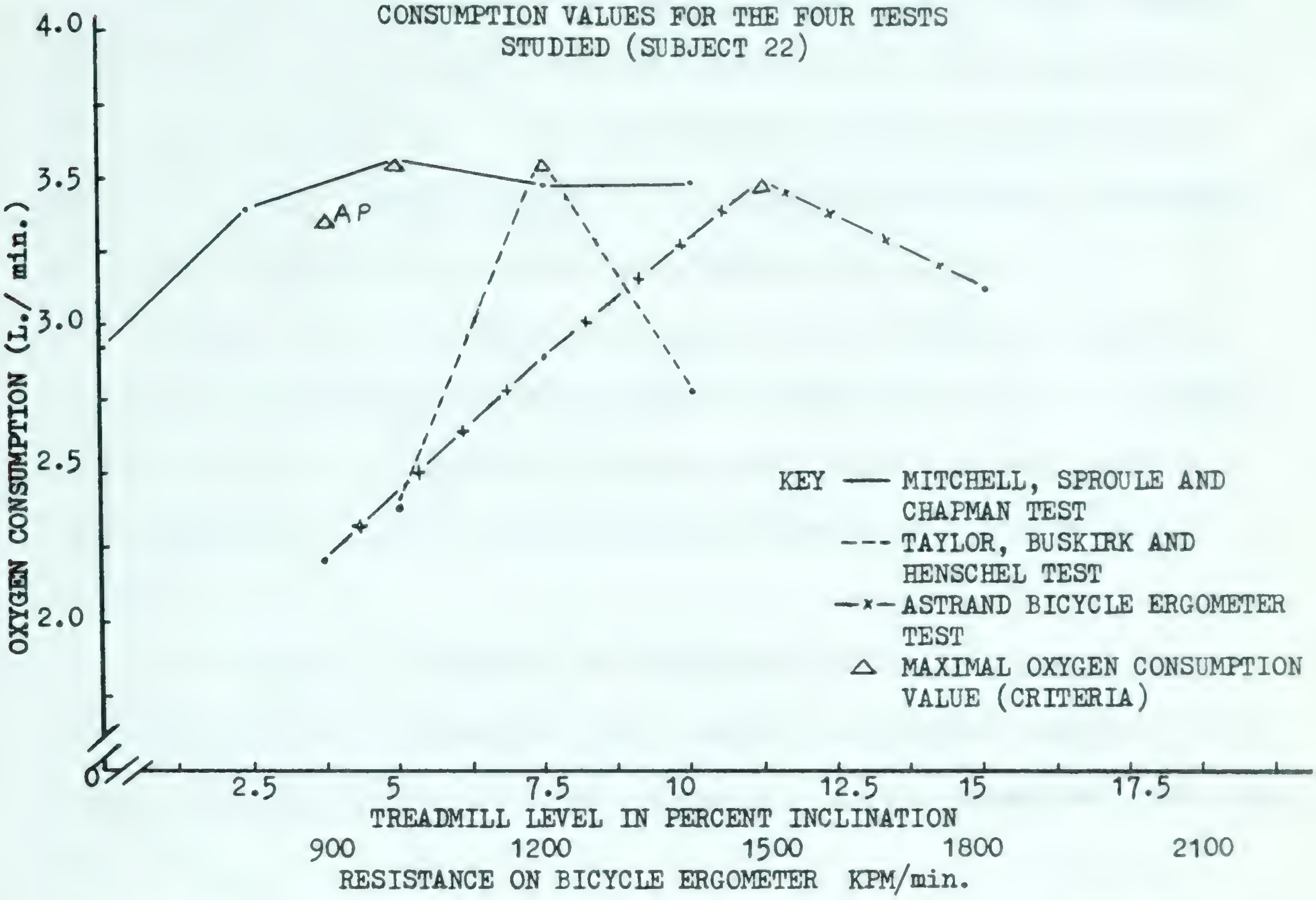
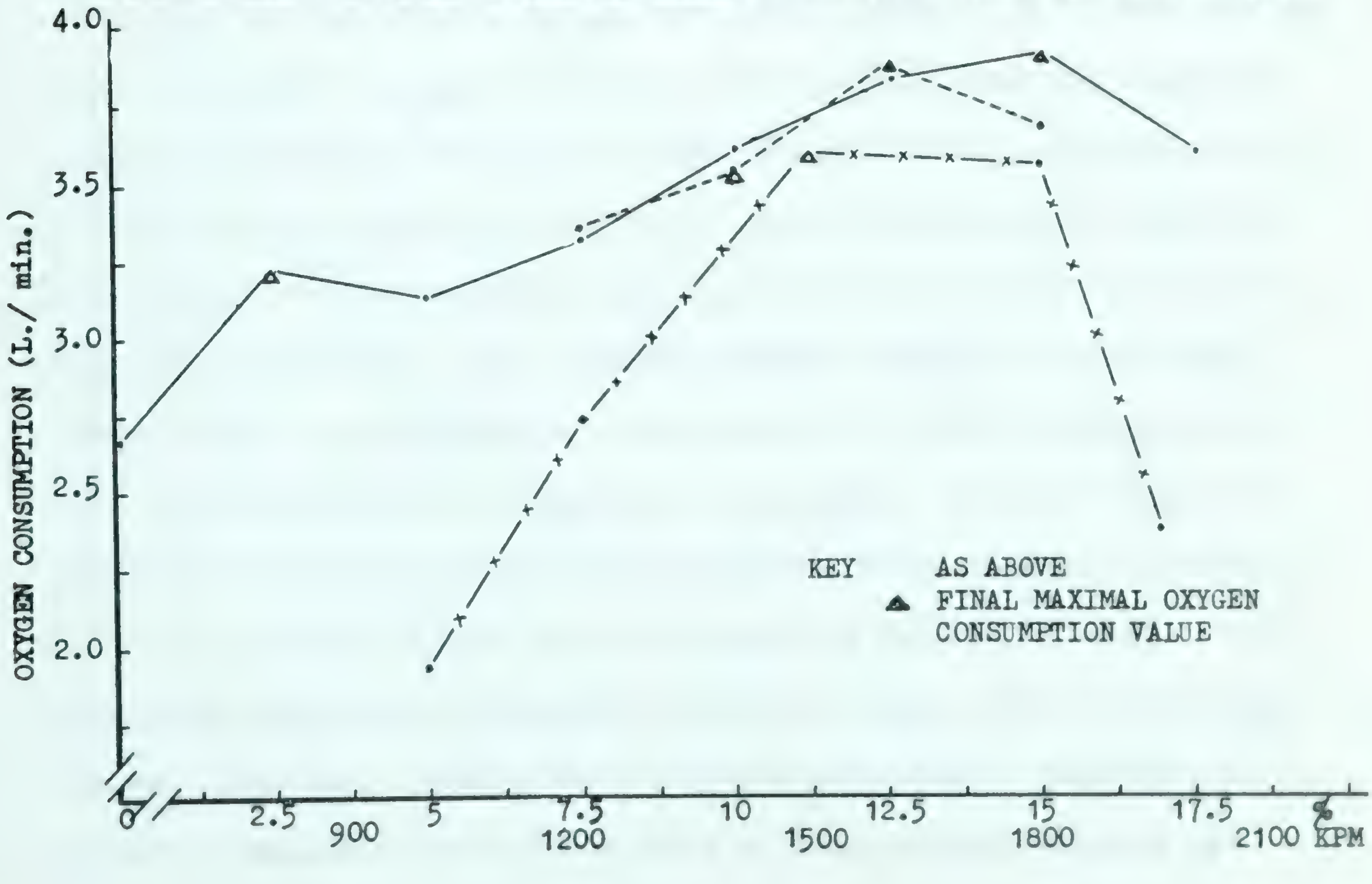


FIGURE XI THREE PATTERNS OF OXYGEN CONSUMPTION VALUES RESULTING FROM CONTINUED EXERCISE AFTER A MAXIMAL OXYGEN CONSUMPTION VALUE HAD BEEN OBTAINED



Laboratory determinations of aerobic capacity can be made by having work with varying loads performed on a treadmill, bicycle ergometer or other types of apparatus. Such determinations require expensive equipment and lengthy testing periods (5, 56, 75) and furthermore, the subject must exert himself to the utmost twice during this period.

Primarily for these reasons tests have been developed for predicting aerobic capacity using information about heart rate (3, 11, 29) and/or the respiratory quotient (47) during work. This approach requires only submaximal work for a brief period and few or even single work sessions.

In an attempt to validate the submaximal or predictive-type test, twenty-four healthy, physically active male subjects were tested on three direct measures of maximal oxygen consumption and one submaximal predictive test (11).

The mean uptake values obtained on the tests were 3.752 ± 0.467 liters per minute on the Mitchell _et al_. test (56), 3.758 ± 0.327 liters per minute on the Taylor _et al_. test (75), 3.485 ± 0.402 liters per minute on the modified Astrand test (5) and 3.714 ± 0.837 liters per minute on the Astrand-Ryhming nomogram test (3, 11). Buskirk and Taylor's figure for an eighteen to twenty-nine year group of sedentary students and soldiers was 3.44 ± 0.460 (21). For fifteen subjects studied by Mitchell and others (56), the corresponding figure was 3.37 ± 0.510 liters per minute. These groups were not actively in training. Astrand's value for thirty-three Swedish athletes aged twenty to twenty-nine (4.15 ± 0.36 liters per minute) (6) and that of Astrand and Saltin (12) 4.23 to 4.66 liters per minute were presumably determined to some extent by the high degree of physical training their subjects had reached. Buskirk and Taylor's comparable figure for a group of young trained subjects was

3.95 ± 0.430 liters per minute (21). von Döbeln _et al._ (80) administered the Astrand-Ryhming nomogram test to 292 active Swedish Air Force pilots aged twenty to twenty-nine and obtained a figure of 3.54 ± 0.040 liters per minute and to 165 pilot applicants between the ages of seventeen and twenty-one. The mean value for the latter group was 2.88 ± 0.040 liters per minute.

The fact that the subjects used by Mitchell _et al._ (56) were required to grip a supporting shelf with one hand during the course of the test may partly explain the difference between their mean value and that obtained in this study. Since maximal oxygen consumption is an objective measure by which one gains insight into the physical fitness of an individual as reflected by his cardiovascular system it would seem quite appropos to attribute the differences in the means obtained on the same tests by different experimentors to the variation in the fitness level of the individuals studied.

Variance analysis disclosed that a significant difference existed between the means of the four tests used in this study. Further analysis indicated that the difference occurred between the mean value obtained on the modified Astrand Bicycle Ergometer test which yielded values lower than those obtained on the other three tests. It seems clear from the work of Taylor, Buskirk and Henschel (75) and Astrand _et al._ (12) that the actual value reached for a given individual depends on the nature of the physical activity. Maximal oxygen consumption is, therefore, maximal relative to a given set of conditions, which should be carefully defined, rather than in an absolute sense.

In areas where bicycles are used by a large fraction of the population the test-retest intra-individual differences in oxygen requirement for a fixed amount of work was small. It is not clear that this will be

the case in areas where bicycle riding is not so popular. Furthermore, the total muscle mass involved in treadmill running and pedalling the bicycle ergometer is, in all likelihood, not equivalent. Astrand and Saltin (12) elicited maximal oxygen uptake values from four subjects by subjecting them to a) prolonged work on a horizontal treadmill, b) prolonged work on a treadmill with the grade set at 7.9 per cent and c) an exhausting ride on a bicycle ergometer. The mean maximal oxygen consumption value obtained on the inclined treadmill was significantly higher (p=.05) from that obtained on the bicycle ergometer. Level running and bicycling produced no significant differences. In a study reported by Astrand (6) in 1952 which involved 67 female and male subjects the maximal oxygen uptake was determined for running on a treadmill set at 1.75 per cent and work on a bicycle ergometer. The averages were statistically equal.

The question of local muscular fatigue cannot be ignored in an examination of these results. The complaint from the subjects tested on the bicycle was usually that the legs refused to continue in spite of the fact that the upper body was experiencing only moderate stress. Of the 14 students that continued to perform work after their oxygen consumption levelled off or declined not one was able to elicit a further increase in oxygen consumption despite the increased workload. Three possible explanations are: a) the subjects had reached their "true" physiological limit as far as their ability to consume oxygen for that type of physical activity was concerned, b) the extreme fatigue of the leg muscles (notably the quadriceps) imposed a strongly limiting factor on the ability of the individual to drive his cardiovascular-respiratory system to greater effort. Specificity may impose definite limitations on maximal oxygen consumption values and since Canadians generally are not accustomed

to pedalling a bicycle the question of specificity cannot be ignored. It was subjectively noted that those individuals with heavily muscled legs were able to attain higher worklevels and correspondingly higher maximal oxygen consumption values. Further studies should be carried out to ascertain the correlation between leg strength and maximal oxygen consumption as determined by the bicycle ergometer and the treadmill techniques. A state of near-complete exhaustion was invariably reached by the 29 subjects who performed additional worklevels on the treadmill tests. Local muscular endurance did not seem to be a limiting factor.
c) The work increments of 300 kilopond meters may be so gross as to make it difficult or impossible to detect the true asymptote of the oxygen consumption curve which might be approached more slowly if the increments were smaller. This would also lead to a tendency to underestimate the maximal oxygen consumption in many cases.

Effects of Additional Work on Maximal Oxygen Consumption. Of the 62 subjects tested for the secondary phase of the study, 22 ran additional levels on the Mitchell, Sproule and Chapman test after they had attained a maximal oxygen uptake reading. Of these twenty-two, seven were unable to attain a higher value while fifteen showed improvement with a resultant mean change of 3.346 to 3.756 liters per minute; a difference which is statistically significant at the one percent level of confidence. It should be noted that the latter mean value is remarkably similar to the overall group mean for the Mitchell, Sproule and Chapman test.

In the case of many of these 22 subjects, the criterion value was attained relatively early in the test and at a level which the subject did not find extremely taxing. It seems conceivable that the peripheral musculature may have imposed an early demand on the cardiovascular-respiratory system following which a homeostatic conditioned prevailed.

This tendency toward an early steady state seemed, subjectively speaking, to occur most frequently among the more fit individuals but the tendency was definitely not limited to this group. It would appear to be of value to assign a starting level commensurate with the fitness level of an individual on the basis of some brief objective evaluation in order to offset this tendency among the more fit individuals.

The fact that 15 of the 22 subjects studied in this phase of the study developed a higher maximal oxygen uptake value than that with which they were scored warrants further discussion. Of the 62 subjects tested only 22 could be persuaded to run at higher worklevels. Most of the 40 subjects who did not participate in this portion of the study had experienced a typical progression in their oxygen consumption, i.e., a gradual climb to an asymptote followed by a decline. As a consequence most of these subjects were near complete exhaustion and therefore were unable to continue. There is little doubt that had they continued a further decline would have resulted.

In the case of the Taylor, Buskirk and Henschel test, seven subjects participated in this aspect of the study. Of these seven, an increase in the workload on successive days elicited higher values of oxygen consumption in three cases. The resultant increase in the mean maximal oxygen uptake value was significant at the .05 level of confidence. The reason for this increase is not clear but conceivably it may have been the result of an incorrect starting level which was set on the basis of the fitness index assigned to the individual via the Johnson, Brouha and Darling Test of Physical Fitness. Conversely, it may have been due to the fact that the best fitting curves of oxygen intake plotted against work rate approach their asymptote slowly as was pointed out by Wyndham and his co-authors (88). Because of this slow approach to the asymptote

it would be possible to underestimate the true maximal oxygen intake if one rigorously applied the criterion of a gain of no more than 0.149 liters per minute over two successive trials as outlined by Taylor et al. (75). Taylor et al. (75), in their study on exercise, drew attention to the fact that precise criteria do not exist to establish unequivocally the rate of oxygen intake at which the maximal level is attained.

Comparsion of Correlations. A study conducted in 1961 by Hettinger and others (43) involved a comparison of values scored on the Astrand-Ryhming Nomogram test (in which corrections were made for age) and those obtained on the direct Astrand test (5). The mean predicted maximal oxygen consumption value for 28 American policemen twenty to thirty years was 2.62 liters per minute as opposed to the mean measured maximal oxygen uptake value of 2.38 liters per minute. The difference was statistically significant at the .05 level. While the mean values obtained in the present study are higher in both instances the difference between the actual and predicted score were of the same statistical magnitude.

These findings are not in agreement with the results published by Astrand and Ryhming (11:220). They reported an actual maximal oxygen intake value of 4.11 liters per minute for 27 male subjects as opposed to a value of 4.07 liters per minute obtained by the same individuals on the basis of the nomogram. The subjects used in their study were healthy, well-trained Swedish men who were, in all likelihood, accustomed to this type of work.

The reason for the differences between actual and the predictive-type bicycle ergometer test maximal oxygen uptake values as determined by Hettinger et al. (43) and noted in the present study is not readily apparent but it may be due in part to the fact that the modified Astand-Ryhming nomogram was computed on the basis of studies conducted on well-trained,

bicycle-oriented athletes. Since this is the case a plausible explanation might lie in the different responses of two equally fit individuals to submaximal worklevels and maximal output on the bicycle ergometer. Under the assumption that one subject was a trained cyclist and the other was unaccustomed to this particular type of activity it would appear possible that during the early, submaximal levels the heart rate response of the non-cyclist would closely approximate the response of the cyclist. Thus both would achieve similar predicted maximal oxygen consumption values. As the workloads approached a maximal level, however, the subject who was unaccustomed to this specific activity might experience severe local muscular fatigue, fatigue so severe, in fact, that the pain in the quadriceps and other muscle groups of the legs prohibited further work. Conversely, the subject acquainted with the activity was able to continue with the experiment until he neared total exhaustion. Under such circumstances it would seem conceivable to assume that the subject who neared total exhaustion might attain a higher maximal oxygen consumption value than the subject who was forced to stop due to local muscular fatigue. A similar discussion could be put forward for the question of leg strength and its relative importance in the establishment of a maximal oxygen consumption value.

The correlation coefficients between the four tests of maximal oxygen consumption as well as the physical fitness index proved to be highly significant. In the case of the relationship between the Astrand predictive and the actual test of maximal oxygen uptake this was in agreement with Hettinger and others (43) and de Vries and Klafs (32).

The null hypothesis Ho: $\rho_{12} = \rho_{13}$ was tested completely and proved tenable in all cases. This question was of particular importance in this study since the problem of the validity of the modified Astrand-Ryhming

nomogram was being tested. If one of the four tests indicated a significantly higher correlation with the physical fitness index or if one of the correlation coefficients between the four estimators of maximal oxygen consumption had proven to be significantly higher or lower, a greater or lesser amount of confidence might have been placed on that particular test.

Klafs and de Vries (32) found that the relationship between the modified Astrand-Ryhming Nomogram test and the maximal oxygen consumption as determined by a modified direct bicycle ergometer test was 0.736 when the values were expressed in liters per minute and 0.522 when body weight was partialled out. In this study, the correlation coefficient between the nomogram test and the modified Astrand Bicycle Ergometer test was 0.65 for the raw scores and 0.62 when body weight was partialled out. When raw scores were used the nomogram test correlated at 0.80 with the Johnson, Brouha and Darling test of Physical Fitness, 0.72 with the Taylor, Buskirk and Henschel test and 0.78 with the Mitchell, Sproule and Chapman test. Correlations between the indirect test and the latter three tests were of the same statistical magnitude when the scores were expressed as milliliters of oxygen consumed per kilogram of body weight per minute.

The moderately high correlation that was noted between the nomogram test and the fitness test may, in part, be due to the fact that both use heart rate information for the establishment of their resprective values. The nomogram utilizes knowledge of cardiac response to submaximal work whereas the Johnson, Brouha and Darling fitness index is based on time run on a treadmill and recovery heart rate following this period of exertion.

It is recognized that a statistically significant relationship exists between fat-free body weight and maximal oxygen uptake (20, 21, 27, 31, 86) but this parameter will not be discussed in this study since it was not one of the basic parameters considered in the limitations formerly outlined.

<u>Variance Discrepancy of the Astrand-Ryhming Nomogram Test</u>. The significantly greater variance, and thus standard deviation, of the Astrand-Ryhming indirect test with respect to the other three tests has not been previously reported.

The Friedman two-way analysis of variance by ranks (37:272), a non-parametric test for k correlated samples, was performed in an attempt to determine if the heterogeneity of variances would lead to misleading conclusions when the test of significance used was based on parametric statistics. This distribution-free test also lead to the rejection of the null hypothesis that the four test means were equal (p = .01) and further analyses substantiated the conclusion based on the parametric test that the direct Astrand Bicycle Ergometer technique yielded a lower mean than did the other three techniques. No other significant differences were found.

From the results of this study it would seem that if the Astrand-Ryhming nomogram is to be used extensively in predicting maximal oxygen consumption the discrepancy in variances should be further investigated. It may be that the greater variability of the nomogram test is not as significant as it would appear from this study but rather that the variances of the other three tests are actually being underestimated due to the imposed criteria of maximal oxygen uptake, or due to the large work increments of the direct tests, notably the direct bicycle ergometer test.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study was to make a direct comparison between the maximal oxygen consumption values obtained on three of the more commonly used tests of this capacity as well as a comparison of these values with a "predicted" value of the maximal oxygen consumption as determined by the modified Astrand-Ryhming nomogram. The tests employed were: the Mitchell, Sproule and Chapman Maximal Oxygen Intake test, the Taylor, Buskirk and Henschel Treadmill test of Maximal Oxygen Consumption, the modified Astrand Bicycle Ergometer test of Maximal Oxygen Uptake and the modified Astrand-Ryhming Nomogram for the Prediction of Maximal Oxygen Uptake from Submaximal Work.

Twenty-four healthy, physically active male subjects were used in this study with the total being comprised of volunteer students and staff members of the University of Alberta as well as soldiers stationed at Griesbach Barracks, Edmonton, Alberta. The ages of the subjects ranged from 17 to 33 years. Permutations were used to obtain a random testing sequence and the subjects and sequences were matched by a chance procedure.

Subjects were permitted to practice on the treadmill and the bicycle ergometer in order to minimize the learning factor and prior to the initial testing every subject performed the Johnson, Brouha and Darling Test of Physical Fitness for Strenuous Exercise. The tests were conducted so that a minimum interval of two days and a maximum interval of seven days occurred between each successive test.

The gas samples were analysed on a Godart Capnograph carbon dioxide analyser and a Beckman #E-2 oxygen analyser. Comparisons were made between the gas analysers and the Scholander method (69). Douglas bags were used to capture the required samples.

The modified Astrand Bicycle Ergometer test yielded a mean maximal oxygen consumption value that was significantly smaller than that obtained on the other three tests ($p = .05$). All other differences were statistically insignificant.

Correlation coefficients resulting from a comparison of the four maximal oxygen uptake tests and the Johnson, Brouha and Darling test were highly significant ($p = .01$) and no correlation was statistically different from any other.

On the basis of the statistical analysis the following conclusions appear to be justified:

1. For the population studied treadmill tests yielded higher mean values of maximal oxygen uptake than did the direct bicycle ergometer test used in this study.

2. The modified Astrand-Ryhming Nomogram test yielded maximal oxygen uptake values equivalent to those obtained on the treadmill tests.

3. The Astrand-Ryhming test produced a significantly larger variance than did any of the three direct tests of maximal oxygen uptake.

4. The correlation coefficients between values obtained on the Astrand-Ryhming indirect test and those on the Johnson, Brouha and Darling fitness test were not significantly different from the correlations obtained between the three direct tests of maximal oxygen uptake and the fitness test.

5. The relationship between the nomogram values and any one set of values determined by a direct technique was as good as the relationship between the values of any two direct measures examined in this study.

6. The present criteria used for the establishment of a maximal oxygen uptake value on the two treadmill tests studied do not necessarily provide a "true" maximum estimation of this ability for all of the members of the population studied.

<u>Recommendations</u>

During the course of the experiment several further studies became apparent as possible means to further clarify the question of the specificity of maximal oxygen consumption. The following studies are, therefore, recommended:

1. A study to determine the relationship between leg strength and maximal oxygen consumption as determined by both a treadmill and a bicycle ergometer test.

2. The effect of training on a bicycle ergometer and a treadmill on the maximal oxygen consumption in order to determine if a reduction of local muscular fatigue can improve the maximal oxygen consumption.

3. An Electrocardiogram study should be conducted to determine whether the heart rate response to the warm-up prior to the Mitchell, Sproule and Chapman test can be used to allocate an appropriate starting level for a subject, i.e. the lower the heart rate at the end of the ten minute warm-up, the higher the level of test commencement.

4. A study to determine the effect of a standardized warm-up on the maximal oxygen consumption as determined by both treadmill and bicycle ergometer tests.

5. A longitudinal study to determine the effect of various types of training on the cardiac output and stroke volume as well as maximal oxygen consumption.

6. Further investigation of the best fitting curves of oxygen uptake plotted against work rate should be conducted to ascertain typical approaches to the asymptote and to determine if certain types of curves are more typical of one type of individual than another.

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APPENDIX A

STATISTICAL TREATMENT

STATISTICAL TREATMENT

Correlation Coefficients. Correlation coefficients between the four maximal oxygen consumption tests and the Johnson, Brouha and Darling Physical Fitness test were obtained by use of the following IBM program.

PROGRAM: 1620-013 Simple Correlations

STATEMENT OF PROBLEM: Given N sets of observations $(X_{i1}, X_{i2}, \ldots, X_{ip})$, $i = 1,2,\ldots,N$, on p random variables. $X_1, X_2, \ldots, X_p$, it is required to compute

(a) means, $X_j = \frac{1}{N} \sum_{i=1}^{N} X_{ij} \quad , j = 1,2,..,p$

(b) variances, $s_j^2 = \frac{1}{N-1} \sum_i X_{ij}^2 - \frac{1}{N}\left(\sum_i X_{ij}\right)2 \quad , j = 1,2,\ldots,p$

(c) standard deviations, s_j , $j = 1,2,\ldots,p$

(d) correlation coefficients,

$$r_{jk} = \frac{\frac{1}{N-1}\left[\sum_i X_{ij}X_{ik} - \frac{1}{N}\sum_i X_{ij} \sum_i X_{ik}\right]}{s_j s_k}$$

$j = 1,2,\ldots,p-1$

$k = j+1,\ldots,p$

Significance of the Difference Between Two Correlation Coefficients for Correlated Samples. To test the difference between any two correlations based on correlated samples a t value was calculated by the formula (83:257):

$$t = \frac{(r_{12} - r_{13}) \sqrt{(N-3)\,(1+r_{23})}}{\sqrt{2(1 - r_{12}^2 - r_{13}^2 - r_{23}^2 + 2r_{12}r_{13}r_{23})}}$$

The t was tested for significance with N-3 degrees of freedom.

Analysis of Variance. An analysis of variance designed to test the significance of the difference between means obtained from correlated groups (two criteria of classification) was used in this study (39:291).

No.	MSC	TBH	AA	AP	$\sum_{r=1}^{4} X$	$\sum_{r=1}^{4} X^2$
1	3.841	4.046	3.598	3.982	15.467	59.925
2	4.024	3.850	3.478	4.240	15.529	61.089
3	3.743	3.834	3.448	3.074	14.099	50.048
. . .	. . .	. . .	. . .	. . .	. . .	. . .
24	4.347	4.001	3.574	4.712	16.634	69.881
$\sum_{i=1}^{24}$	90.036	90.186	83.646	90.130	$X_{..}=352.998$	$\sum\sum X^2 = 1326.53$
$\sum_{i=1}^{24} X^2$	342.795	341.359	295.243	347.133		

A. Sum of Squares

1. Correction. $\dfrac{(\sum X)^2}{N} = \dfrac{(352.998)^2}{96} = 1297.996$

2. Total Sum of Squares Around the General Mean.

$$SS_T = (3.841^2 + 4.024^2 + \ldots + 4.712^2) - 1297.996$$
$$= 1326.53 - 1297.996 = 28.534$$

3. Sum of Squares Between the Means of Tests.

$$SS_{trials} = \underline{(90.036)^2 + (90.186)^2 + (83.646)^2 + (89.130)^2}$$
$$= 1299.20 - 1297.996 = 1.204$$

4. Sum of Squares Among the Means of Subjects.

$$SS_{subjects} = \frac{(15.467)^2 + (15.529)^2 + \ldots + (16.634)^2}{4}$$
$$= 1317.227 - 1297.996 = 19.231$$

5. Interaction Sum of Squares.

$$\text{Interaction SS} = SS_T - (SS_{subjects} + SS_{trials})$$
$$= 28.534 - (19.231 + 1.204) = 8.099$$

B. Analysis of Variance

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F
Between tests	1.204	(C-1)=(4-1)=3	$\frac{1.204}{3} = .401$	$\frac{.401}{.117} = 3.427$
Among Subjects	19.231	(R-1)=(24-1)=23	$\frac{19.231}{23} = .836$	$\frac{.836}{.117} = 7.145$
Interaction	8.099	(R-1)(C-1)=(23)(3)=69	$\frac{8.099}{69} = .117$	
Total	28.534	95		

Tests		Subjects	
Degrees of freedom	= 3/69	Degrees of freedom	= 23/69
F at .05	= 2.74	F at .05	= 1.67
F at .01	= 4.07	F at .01	= 2.07

Duncan's New Multiple-Range Test. The new Duncan Multiple-Range test (78:107) was developed in 1955 and is designed to permit comparison of each treatment mean with every other treatment mean.

$$S_{\bar{x}} = \sqrt{\frac{(\text{error mean square})}{r}}$$

Least Significant Ranges (R) (.05)

Value of p	2	3	4
Significant Studentized Ranges	2.81	2.95	3.05
Rp = ($S_{\bar{x}}$ SSR) = Least Significant Range	2.627	2.768	2.861

df = (r-1) (c-1)

Rank of Means
(milliliters of oxygen consumed per minute per kilogram of body weight)

46.31 49.30 49.86 50.02

Method of Testing the Difference

Largest - Smallest	= 50.02 - 46.31 = 3.71	2.861	Significant
Largest - Second Smallest	= 50.02 - 49.30 = 0.72	2.768	Not Significant
. . . .			
Second Smallest - Smallest	49.30 - 46.31 = 2.99	2.627	Significant

Significance of the Difference Between Two Means For Correlated Samples.

$$S_D^2 = \frac{\sum D^2}{N-1} - \bar{D}^2$$

$$S_{\bar{D}}^2 = \frac{S_D^2}{N}$$

$$t = \frac{\bar{D}}{S_{\bar{D}}} = \frac{\bar{D}}{\sqrt{\frac{S_D^2}{N}}}$$

degrees of freedom = N-1

Standard Deviation.

$$s = \sqrt{\frac{X^2}{N} - \bar{X}^2}$$

Significance of a Correlation Coefficient.

$$t = r\sqrt{\frac{N-2}{1-r^2}}$$

degrees of freedom = N-2

APPENDIX B

INDIVIDUAL SCORE SHEETS

Name:	Age:	Wt.	Ht.	Max. VO_2	1. Astrand.	Ast. Pred.	T.B.H.	M.S.C.		Resting HR.
Address:	Smokes:			Dates:	——	——	——	——	——	——
Phone:				R.Q.						

ASTRAND NOMOGRAM

Load kpm.	Pulse rates (after mins. of work) 1	2	3	4	5	6	7	8	9	10
900										
1200										

Prediction : L./min.

,, : ml./Kg.B.W.

ASTRAND MAX VO_2 TEST.

Load kpm.	Exercise P.R. (mins.) Pre	1	2	3	4	5	6	Sub-M VO_2	Recovery P.R. 15s	30	45	1	1.30	2	3.0	4	5			
600																				
900																				
1200																				
1500																				
1800																				
1950																				
2100																				

Max: L./min. ml./kg.B.W.

Work done at MaxVO_2: kpm. Max P.R.

JOHNSON-BROUHA RUN : Date / /

Max. P.R.:

Duration of run: secs.

a	15	30	45	1	1.30	2	2.30	3	3.30	4	4.30	5		15	30	45	1	1.30	2	2.30	3	3.30	4	4.30	5		1-1.30	2-2.30	3-3.30	PFI = $\frac{00}{2x}$ =

GAS ANALYSIS SHEET

300 KPM
600
900
1200
1500
1800
1950
2100

NAME ______________________

DATE ______________________

T = __________ °C
B.P. = __________ mm. Hg
Factor = __________

FeO_2 = __________ X $\frac{2.5}{1000}$ = __________ F_IO_2 = 20.94

FeO_2 = __________ (corr.) F_ICO_2 = 00.03

$FeCO_2$ = __________ F_IN_2 = 79.03

FeN_2 = __________

V_EATPS = __________ l./min.

V_ESTPD = __________ X __________ = __________ l./min.

V_ISTPD = __________ X $\frac{\text{__________}}{.7903}$ = __________ l./min.

VO_2 = (__________ X .2094) - (__________ X __________) = __________ l./min.

VCO_2 = (__________ X ______) - (__________ X .0003) = __________ l./min.

R. Q. = __________

Smoker __________ Number __________

Health (general) __________

Height __________ inches

Weight __________ pounds __________ kilograms

Birthday __________

APPENDIX C

RAW SCORES

JOHNSON, BROUHA AND DARLING

PHYSICAL FITNESS SCORES

Subject	Fitness Score	Subject	Fitness Score	Subject	Fitness Score
1	76.1	9	79.8	17	82.0
2	60.2	10	90.4	18	83.8
3	59.4	11	77.7	19	52.8
4	82.9	12	60.4	20	43.3
5	50.2	13	86.7	21	54.3
6	102.7	14	38.9	22	59.5
7	79.0	15	47.2	23	75.0
8	68.8	16	69.7	24	102.0

MEAN STEADY STATE HEART RATE FOR THE PREDICTION OF

MAXIMAL OXYGEN UPTAKE FROM THE ASTRAND-RYHMING NOMOGRAM

Subject	Mean Heart Rate	Resistance kpm	Subject	Mean Heart Rate	Resistance kpm
1	133	900	13	132	900
2	132	900	14	153	600
3	158	900	15	163	900
4	149	1200	16	143	900
5	157	900	17	132	900
6	132	1200	18	135	900
7	136	900	19	167	900
8	134	1200	20	170	900
9	131	900	21	149	900
10	136	1200	22	149	900
11	143	1200	23	135	900
12	158	900	24	145	1200

CALCULATION OF MAXIMUM OXYGEN UPTAKE FROM PULSE RATE AND WORKLOAD ON A BICYCLE ERGOMETER (3)

Working Pulse	Maximal Oxygen Uptake (L./min.) 300 kpm/min.	600 kpm/min.	900 kpm/min.	1200 kpm/min.
120	2.2	3.5	4.8	
121	2.2	3.4	4.7	
122	2.2	3.4	4.6	
123	2.1	3.4	4.6	
124	2.1	3.3	4.5	6.0
125	2.0	3.2	4.4	5.9
126	2.0	3.2	4.4	5.8
127	2.0	3.1	4.3	5.7
128	2.0	3.1	4.2	5.6
129	1.9	3.0	4.2	5.6
130	1.9	3.0	4.1	5.5
131	1.9	2.9	4.0	5.4
132	1.8	2.9	4.0	5.3
133	1.8	2.8	3.9	5.3
134	1.8	2.8	3.9	5.2
135	1.7	2.8	3.8	5.1
136	1.7	2.7	3.8	5.0
137	1.7	2.7	3.7	5.0
138	1.6	2.7	3.7	4.9
139	1.6	2.6	3.6	4.8
140	1.6	2.6	3.6	4.8
141		2.6	3.5	4.7
142		2.5	3.5	4.6
143		2.5	3.4	4.6
144		2.5	3.4	4.5
145		2.4	3.4	4.5

Working Pulse	Maximal Oxygen Uptake (L./min.) 300 kpm/min.	600 kpm/min.	900 kpm/min.	1200 kpm/min.
146		2.4	3.3	4.4
147		2.4	3.3	4.4
148		2.4	3.2	4.3
149		2.3	3.2	4.3
150		2.3	3.2	4.2
151		2.3	3.1	4.2
152		2.3	3.1	4.1
153		2.2	3.0	4.1
154		2.2	3.0	4.0
155		2.2	3.0	4.0
156		2.2	2.9	4.0
157		2.1	2.9	3.9
158		2.1	2.9	3.9
159		2.1	2.8	3.8
160		2.1	2.8	3.8
161		2.0	2.8	3.7
162		2.0	2.8	3.7
163		2.0	2.8	3.7
164		2.0	2.7	3.6
165		2.0	2.7	3.6
166		1.9	2.7	3.6
167		1.9	2.6	3.5
168		1.9	2.6	3.5
169		1.9	2.6	3.5
170		1.8	2.6	3.4

INFORMATION PERTAINING TO INDIVIDUAL SUBJECT'S PHYSICAL CHARACTERISTICS

Subject	Age	Height (Inches)	Weight		Smoker			
			Pounds	Kilograms	Yes	No	5	5
1	23	68	154.5	70.08		X		
2	20	69.5	178.25	80.85		X		
3	19	71	180	81.65		X		
4	23	78	189	86.73		X		
5	25	70	163	73.94		X		
6	33	73	170.5	77.34		X		
7	24	71	172	78.02		X		
8	25	68.5	170.5	77.34	Pipe			
9	30	71	163	73.94	X		X	
10	23	73	170	77.11		X		
11	26	69.5	168	76.20		X		
12	29	74	177	80.29		X		
13	22	70.5	170	77.11		X		
14	18	69	139	63.05	X			X
15	22	72	169	76.66		X		
16	25	71.75	184	83.46		X		
17	23	70	170	77.11		X		
18	24	67.5	156	70.76		X		
19	17	69	145.5	65.00	X			X
20	29	67	155	70.31		X		
21	21	69	168	76.20		X		
22	21	70	173	78.47	X			X
23	18	72.5	148	67.13		X		
24	21	69	153	69.40		X		
25	20	70.25	160	72.58	X			X
26	26	69	185	80.92		X		
27	17	67.5	150	68.03	Pipe			
28	22	69	146	66.23	X			X
29	19	73	194	87.00	X			X
30	19	65	119	53.98	X			X
31	17	70	204	92.53		X		
32	21	67.75	148	67.13	X			X
33	17	66	137.5	62.37	X			X
34	20	72	181.5	82.33		X		
35	25	70.5	175	79.38		X		
36	25	70.25	170	77.11		X		
37	17	68.5	142	64.41	X			X
38	23	72	165.5	75.07		X		
39	21	67	147.5	66.90	X			X
40	21	72	157	71.21	X			X
41	25	66	147.5	66.91		X		
42	24	70	212.5	96.39		X		
43	35	68	168	76.20	X		X	
44	24	73	203	92.08	X			X
45	19	71.5	182	82.55	X			X
46	23	68.5	157	71.21	X			X
47	28	72.5	205	92.99		X		
48	20	71	151	68.49		X		
49	20	67	150	68.04		X		
50	22	67	142.5	64.67	X			X
51	25	67.5	154	69.85		X		
52	17	67.75	142	64.41		X		
53	20	63	142	64.41		X		
54	34	64.5	142	64.41	X			X

Subject	Age	Height (Inches)	Weight		Smoker			
			Pounds	Kilograms	Yes	No	5	5
55	26	68	158	71.67	X			X
56	22	68.5	154	69.85		X		
57	18	70.5	147.5	66.91	X			X
58	18	69.5	166	75.15	X			X
59	44	69	153.5	69.40		X		
60	38	65.75	143	64.86	X			X
61	38	68	149.5	67.81	X			X
62	42	66	180	81.65	X			X
63	48	67.5	141	63.96	X			X

CORRECTIONS FOR AMERICAN METER CO. GAS METER #802

This meter was tested for its volume determinations using as standards the large Tissot tank in the Faculty of Physical Education Laboratory and a smaller Tissot in the Cardio-pulmonary Laboratory at the University Hospital. It was found to be recording volume readings in excess of actual volumes pumped, as indicated by the Tissot tanks. A second American Meter Co. gas meter, in use in the University Hospital, was found to give extremely accurate readings when compared to the same Tissot tanks.

The data collected was analyzed and a regression equation calculated. This equation was found to be,

$$Y = .22770 + .943099\ X$$

where Y = corrected volume

and X = volume as read on the American Meter Co. Gas Meter #802.

This regression equation was then used to calculate a complete set of correction tables. These tables also incorporate a factor for loss of volume during oxygen and carbon dioxide analysis, with the factor being considered as 300 c.c.

CORRECTIONS FOR THE BECKMAN E-2 OXYGEN ANALYZER.

The accuracy of this instrument was tested against two micro-Scholander instruments operated by laboratory technicians in the Cardio-pulmonary Laboratory of the University of Alberta Hospital and the laboratory of the Department of Physiology at the University of Alberta.

The values obtained with the two Scholanders were averaged and a regression equation based on the Beckman reading and the Scholander values was calculated. This equation was found to be,

$$Y' = .893X + 2.22$$

where Y' = the corrected percentage of oxygen

and X = the percentage of oxygen as read on the Beckman E-2 analyzer.

The discrepancy was found to be due to impure nitrogen which was used as a calibration gas.

Based on the above regression equation, a second regression line was calculated which permitted direct correction of oxygen consumption values. This equation was found to be,

$$Y' = .871X + .0044$$

where Y' = corrected oxygen consumption in liters per minute

and X = oxygen consumption value obtained on the basis of the uncorrected percentage of oxygen as obtained on the Beckman analyzer.

After testing with the same Micro-Scholanders, the Godart Capnograph infra-red carbon dioxide analyzer was found to give accurate readings.

The raw scores contained in Appendix C have not been corrected for the oxygen discrepancy but have been changed to the corrected volume.

RAW SCORES OBTAINED ON THE
MITCHELL, SPROULE AND CHAPMAN
MAXIMAL OXYGEN INTAKE TEST

SUBJECT		PERCENT OF TREADMILL INCLINATION								
		0%	2½%	5%	7½%	10%	12½%	15%	17½%	20%
1.	$\%O_2$	14.69	15.68	15.71	15.18	15.33	15.98	16.30	16.76	
	$\%CO_2$	5.10	4.60	4.45	4.95	5.10	4.65	4.40	3.90	
	V_ESTPD	42.63	58.26	62.65	66.37	79.97	86.35	93.60	107.65	
	VO_2	2.798	3.171	3.411	3.972	4.198	4.360	4.410	4.588	
2.	$\%O_2$	16.03	16.00	16.04	16.11	16.05	16.10	17.23		
	$\%CO_2$	4.30	4.25	4.40	4.20	4.60	4.40	3.60		
	V_ESTPD	65.78	73.69	78.20	85.39	92.79	90.20	125.48		
	VO_2	3.341	3.781	3.941	4.273	4.615	4.479	4.701		
3.	$\%O_2$	15.94	15.90	16.10	16.04	16.55	17.01	17.21	17.66	
	$\%CO_2$	4.60	4.40	4.30	4.40	4.25	3.90	3.60	2.80	
	V_ESTPD	64.31	67.72	77.26	85.16	95.03	111.23	114.41	151.62	
	VO_2	3.289	3.532	3.857	4.292	4.214	4.388	4.316	5.178	
4.	$\%O_2$	15.30	15.10	15.09	15.35	15.54	15.88	16.34		
	$\%CO_2$	4.65	4.80	4.90	4.80	4.90	4.70	4.50		
	V_ESTPD	58.46	61.69	64.50	73.64	79.50	87.14	91.77		
	VO_2	3.454	3.779	3.941	4.276	4.404	4.499	4.253		
5.	$\%O_2$	15.95	16.00	16.08	16.50	16.80	17.41	17.35		
	$\%CO_2$	4.40	4.35	4.40	4.20	4.25	3.50	3.00		
	V_ESTPD	50.57	56.44	67.42	75.26	85.47	103.54	108.37		
	VO_2	2.607	2.880	3.365	3.396	3.520	3.672	4.067		
6.	$\%O_2$	16.50	17.00	16.36	16.39	17.31	16.84	17.40	17.71	
	$\%CO_2$	3.80	3.60	4.10	4.10	3.30	3.90	3.40	2.90	
	V_ESTPD	77.01	94.78	81.99	91.32	121.98	112.44	136.83	71.15	
	VO_2	3.555	3.826	3.977	4.272	4.545	4.679	4.907	2.367	
7.	$\%O_2$	14.02	14.60	15.20	15.31	15.20	16.16	16.73	17.31	
	$\%CO_2$	5.30	5.30	5.10	5.20	5.30	4.90	4.40	3.50	
	V_ESTPD	44.25	50.71	59.44	71.94	76.07	97.23	112.18	121.65	
	VO_2	3.154	3.360	3.517	4.138	4.461	4.625	4.675	4.468	

$\%O_2$ - Percentage of oxygen in the expired air.
$\%CO_2$ - Percentage of carbon dioxide in the expired air.
V_ESTPD - Total volume of gas expired at standard temperature and pressure, dry.
VO_2 - The amount of oxygen consumed.

SUBJECT	PERCENT OF TREADMILL INCLINATION								
	0%	2½%	5%	7½%	10%	12½%	15%	17½%	20%
8.									
%O_2	15.70	15.73	16.10	16.45	16.48	16.86	17.13	17.13	
%CO_2	4.30	4.30	4.10	3.90	4.00	3.75	3.50	2.40	
V_ESTPD	61.59	65.36	78.07	89.98	92.99	110.36	122.00	95.25	
VO_2	3.386	3.569	3.938	4.189	4.269	4.607	4.757	3.993	
9.									
%O_2	15.70	15.85	15.85	15.44	16.11	16.13	16.71	17.22	17.35
%CO_2	4.50	4.35	4.35	4.80	4.40	4.50	3.95	3.50	2.30
V_ESTPD	53.04	58.48	62.95	63.32	75.08	79.54	94.98	111.15	85.28
VO_2	2.888	3.096	3.332	3.604	3.719	3.897	4.095	4.208	3.359
10.									
%O_2	14.63	14.31	14.30	14.38	14.78	15.34	15.60	16.63	
%CO_2	5.40	5.50	5.80	5.60	5.60	5.20	5.10	4.10	
V_ESTPD	47.84	51.99	55.46	62.84	70.50	86.81	94.24	121.25	
VO_2	3.138	3.606	3.810	4.288	4.454	4.960	5.099	5.315	
11.									
%O_2	15.66	15.35	15.06	15.38	15.93	15.98	16.58	17.28	
%CO_2	4.40	4.40	4.80	4.60	4.60	4.60	4.05	3.30	
V_ESTPD	49.46	52.18	54.91	62.33	76.18	80.78	94.73	108.23	
VO_2	2.731	3.086	3.390	3.629	3.905	4.090	4.216	4.072	
12.									
%O_2	16.14	16.09	16.05	16.14	16.30	16.75	16.88		
%CO_2	4.40	4.25	4.30	4.30	4.35	3.90	3.20		
V_ESTPD	58.36	65.47	69.68	73.49	86.30	99.62	78.25		
VO_2	2.862	3.284	3.522	3.630	4.078	4.242	3.348		
13.									
%O_2	15.75	16.05	16.10	16.15	16.48	16.74	17.09	17.28	
%CO_2	4.40	4.00	4.10	4.10	4.00	3.80	3.80	3.20	
V_ESTPD	54.31	65.28	68.72	79.71	95.75	106.61	123.13	125.32	
VO_2	2.936	3.351	3.466	3.971	4.394	4.599	4.766	4.750	
14.									
%O_2	16.08	15.78	16.16	16.50	16.91	17.18			
%CO_2	4.40	4.50	4.20	4.20	4.10	4.05			
V_ESTPD	57.05	56.13	62.52	75.82	86.69	89.23			
VO_2	2.846	2.999	3.089	3.421	3.485	3.294			
15.									
%O_2	16.15	15.90	16.00	16.18	16.49	16.83	17.59		
%CO_2	4.30	4.45	4.40	4.40	4.30	4.10	3.30		
V_ESTPD	54.12	57.05	63.59	70.13	82.02	95.07	113.11		
VO_2	2.668	2.970	3.238	3.411	3.690	3.926	3.812		
16.									
%O_2	15.29	14.86	15.19	15.81	15.93	16.03	16.59		
%CO_2	4.80	4.90	4.90	4.60	4.60	4.60	4.20		
V_ESTPD	53.40	57.58	68.35	83.01	86.98	98.13	105.63		
VO_2	3.141	3.685	4.089	4.382	4.458	4.906	4.645		

SUBJECT	PERCENT OF TREADMILL INCLINATION								
	0%	$2\frac{1}{2}$%	5%	$7\frac{1}{2}$%	10%	$12\frac{1}{2}$%	15%	$17\frac{1}{2}$%	20%
17.									
$\%O_2$	15.23	14.90	14.91	15.21	15.40	15.45	15.95	16.74	
$\%CO_2$	4.20	4.55	4.75	4.60	4.70	4.90	4.60	4.20	
V_ESTPD	47.23	49.64	63.16	64.59	74.03	78.18	91.68	96.29	
VO_2	2.889	3.197	4.028	3.900	4.271	4.420	4.677	4.053	
18.									
$\%O_2$	16.35	15.96	16.35	16.58	16.85	17.19	17.26	17.44	
$\%CO_2$	4.00	4.30	4.00	3.75	3.65	3.30	3.30	2.60	
V_ESTPD	63.99	71.43	75.23	83.73	98.00	112.87	117.99	109.67	
VO_2	3.042	3.691	3.577	3.793	4.130	4.377	4.470	4.109	
19.									
$\%O_2$	14.43	15.00	15.06	15.45	16.20	16.25	16.94		
$\%CO_2$	5.20	4.80	4.80	4.80	4.40	4.50	4.00		
V_ESTPD	39.29	47.09	52.04	58.17	75.16	79.62	96.50		
VO_2	2.698	2.944	3.211	3.305	3.638	3.780	3.626		
20.									
$\%O_2$	15.36	15.04	15.28	15.83	16.48				
$\%CO_2$	4.85	5.20	5.05	4.90	4.40				
V_ESTPD	49.88	53.03	56.81	68.40	85.43				
VO_2	2.884	3.231	3.145	3.541	3.831				
21.									
$\%O_2$	15.53	15.88	15.80	15.68	15.90	16.35	17.13	17.00	
$\%CO_2$	4.30	4.10	4.40	4.55	4.60	4.20	3.40	2.80	
V_ESTPD	51.47	63.55	66.03	69.87	79.06	93.90	117.88	101.06	
VO_2	2.939	3.383	3.528	3.811	4.083	4.415	4.629	4.296	
22.									
$\%O_2$	15.74	15.66	15.93	15.86	16.05				
$\%CO_2$	4.40	4.55	4.40	4.55	4.20				
V_ESTPD	61.96	70.61	78.33	75.66	78.04				
VO_2	3.358	3.873	4.055	3.957	3.965				
23.									
$\%O_2$	15.81	15.38	15.25	15.39	15.58	15.75	16.05		
$\%CO_2$	4.20	4.60	4.70	4.60	4.60	4.60	4.50		
V_ESTPD	46.64	49.41	56.01	63.35	70.30	79.15	82.75		
VO_2	2.512	2.877	3.338	3.681	3.915	4.238	4.139		
24.									
$\%O_2$	14.33	13.76	15.00	14.93	14.93	15.24	16.00	16.84	
$\%CO_2$	5.30	5.60	5.10	5.20	5.30	5.20	4.80	4.10	
V_ESTPD	46.78	43.69	63.24	67.34	68.86	79.37	97.28	121.36	
VO_2	3.258	3.359	3.903	4.198	4.273	4.635	4.850	4.986	

RAW SCORES FROM MSC FOR SUBSIDIARY PROBLEM

Subject	Percent Inclination of Treadmill									
	0%	$2\frac{1}{2}$%	5%	$7\frac{1}{2}$%	10%	$12\frac{1}{2}$%	15%	$17\frac{1}{2}$%	20%	$22\frac{1}{2}$%
25.										
$\%O_2$	16.14	16.25	16.38	16.75	16.95	17.20				
$\%CO_2$	4.40	4.20	4.10	4.00	3.95	3.70				
V_ESTPD	49.55	66.20	86.40	90.27	101.57	118.09				
VO_2	2.435	3.197	4.053	3.835	4.072	4.440				
26.										
$\%O_2$	15.98	15.45	15.83	15.73	15.95	15.94	16.43	16.98		
$\%CO_2$	4.15	4.30	4.35	4.40	4.60	4.60	4.50	3.80		
V_ESTPD	60.93	62.68	73.60	83.43	84.88	87.51	103.98	103.31		
VO_2	3.158	3.644	3.916	4.533	4.330	4.476	4.700	4.143		
27.										
$\%O_2$	14.55	15.65	14.68	14.63	15.25	15.03	15.70			
$\%CO_2$	5.00	4.85	5.15	5.20	4.85	5.20	4.85			
V_ESTPD	42.81	51.15	51.79	49.28	71.24	73.45	86.34			
VO_2	2.897	2.769	3.399	3.258	4.217	4.485	4.621			
28.										
$\%O_2$	15.45	15.88	15.60	15.76	16.25	16.53	16.88			
$\%CO_2$	4.50	4.10	4.55	4.60	4.30	4.15	3.85			
V_ESTPD	45.71	59.39	61.78	67.14	88.13	90.37	101.17			
VO_2	2.633	3.160	3.394	3.587	4.232	4.054	4.172			
37.										
$\%O_2$	15.08	15.48	15.54	15.94	16.68	16.93	17.06	17.25		
$\%CO_2$	4.50	4.30	4.50	4.50	4.05	4.00	3.80	3.10		
V_ESTPD	30.80	47.03	57.35	63.79	76.46	80.20	90.93	86.68		
VO_2	1.918	2.717	3.237	3.280	3.305	3.224	3.555	3.341		
44.										
$\%O_2$	16.41	16.54	16.66	17.10	17.43	17.60				
$\%CO_2$	4.10	4.05	3.85	3.60	3.40	2.40				
V_ESTPD	70.33	82.25	93.95	106.29	103.76	100.54				
VO_2	3.272	3.701	4.136	4.159	3.682	3.616				
45.										
$\%O_2$	14.91	15.25	15.25	15.60	15.78	16.03	16.68	16.95		
$\%CO_2$	4.90	4.80	4.90	4.90	4.90	4.80	4.00	3.00		
V_ESTPD	56.18	61.59	66.83	71.15	76.16	85.04	90.85	104.45		
VO_2	3.559	3.655	3.947	3.887	3.509	4.207	3.939	4.450		
47.										
$\%O_2$	14.33	14.96	14.99	14.74	15.30					
$\%CO_2$	5.40	5.30	5.20	5.50	5.20					
V_ESTPD	60.12	59.88	71.75	77.58	83.81					
VO_2	4.171	3.694	4.418	4.961	4.832					
48.										
$\%O_2$	13.98	13.58	13.81	13.63	13.73	14.49	15.24	15.93	16.43	15.98
$\%CO_2$	5.10	5.35	5.30	5.95	5.75	5.50	5.30	4.80	4.30	3.60
V_ESTPD	39.35	36.84	43.70	39.40	50.72	65.59	77.96	93.25	105.90	84.75
VO_2	2.936	2.910	3.331	3.025	3.858	4.400	4.532	4.730	4.843	4.516

Subject	0%	2½%	5%	7½%	10%	12½%	15%	17½%	20%	22½%
49.										
$\%O_2$	15.65	15.40	15.56	15.23	15.92	16.25	17.00			
$\%CO_2$	4.70	4.70	4.95	5.20	5.25	4.80	3.70			
V_ESTPD	55.05	51.29	60.58	59.78	70.19	78.43	79.02			
VO_2	3.004	2.959	3.332	3.499	3.486	3.662	3.170			
51.										
$\%O_2$	14.01	13.75	14.34	14.84	15.23	15.81	15.96			
$\%CO_2$	5.70	5.80	5.60	5.60	5.30	4.70	3.40			
V_ESTPD	39.33	42.98	49.54	59.02	71.01	78.62	68.62			
VO_2	2.857	3.252	3.405	3.684	4.138	4.130	3.710			
52.										
$\%O_2$	15.29	15.54	15.50	16.05	16.68					
$\%CO_2$	4.50	4.45	4.50	4.20	4.05					
V_ESTPD	46.27	51.11	58.36	65.09	73.99					
VO_2	2.759	2.892	3.326	3.306	3.198					
56.										
$\%O_2$	15.11	15.38	15.15	15.18	15.48	15.65	16.10	16.45		
$\%CO_2$	5.25	4.80	5.20	4.90	5.00	5.00	4.75	3.90		
V_ESTPD	50.61	55.99	55.54	63.41	72.88	76.30	89.72	92.53		
VO_2	3.032	3.230	3.803	3.803	4.073	4.101	4.372	4.307		
61.										
$\%O_2$	17.15	17.40	17.51	17.73	18.33					
$\%CO_2$	3.30	3.20	3.10	2.90	2.10					
V_ESTPD	65.60	73.01	80.28	77.75	57.62					
VO_2	2.576	2.656	3.642	2.565	1.586					

RAW SCORES OBTAINED ON THE TAYLOR, BUSKIRK AND HENSCHEL TREADMILL TEST OF MAXIMAL OXYGEN CONSUMPTION

Subject	Percent of Treadmill Inclination					
	5%	7½%	10%	12½%	15%	17½%
1.						
$\%O_2$			16.55	16.85	17.29	
$\%CO_2$			4.70	4.40	4.15	
V_ESTPD			93.83	115.26	123.88	
VO_2			4.050	4.628	4.367	
2.						
$\%O_2$			16.58	17.30		
$\%CO_2$			4.50	3.65		
V_ESTPD			101.93	118.67		
VO_2			4.415	4.326		
3.						
$\%O_2$		16.35	16.88			
$\%CO_2$		4.70	4.40			
V_ESTPD		96.26	110.41			
VO_2		4.397	4.393			
4.						
$\%O_2$			16.69	16.65		
$\%CO_2$			4.40	4.90		
V_ESTPD			108.74	99.34		
VO_2			4.586	4.109		
5.						
$\%O_2$	16.83	17.23				
$\%CO_2$	4.40	4.05				
V_ESTPD	89.43	101.68				
VO_2	3.615	3.689				
6.						
$\%O_2$			16.90	16.81		
$\%CO_2$			4.30	4.40		
V_ESTPD			125.77	108.99		
VO_2			5.004	4.432		
7.						
$\%O_2$		16.55	16.26	16.60		
$\%CO_2$		5.10	4.85	4.95		
V_ESTPD		97.62	106.81	112.00		
VO_2		4.110	4.959	4.689		
8.						
$\%O_2$		16.59	17.05			
$\%CO_2$		4.35	4.10			
V_ESTPD		100.10	106.96			
VO_2		4.363	4.110			
9.						
$\%O_2$			16.46	16.05	16.93	16.73
$\%CO_2$			5.10	5.70	4.80	4.80
V_ESTPD			93.52	95.50	113.62	106.38
VO_2			4.043	4.473	4.328	4.322

Subject	5%	$7\frac{1}{2}$%	10%	$12\frac{1}{2}$%	15%	$17\frac{1}{2}$%
10.						
$\%O_2$	14.68	14.33	15.69	15.78		
$\%CO_2$	6.05	6.70	6.00	5.70		
V_ESTPD	71.92	69.21	94.40	94.25		
VO_2	4.548	4.564	4.776	4.682		
11.						
$\%O_2$			16.55	16.93		
$\%CO_2$			4.70	4.70		
V_ESTPD			98.14	102.92		
VO_2			4.235	3.947		
12.						
$\%O_2$	16.48	16.75	16.75	17.25		
$\%CO_2$	4.65	4.50	4.30	3.90		
V_ESTPD	86.95	96.84	93.69	89.38		
VO_2	3.839	3.985	3.907	3.255		
13.						
$\%O_2$			16.70	16.75		
$\%CO_2$			4.45	3.90		
V_ESTPD			107.71	109.14		
VO_2			4.515	4.665		
14.						
$\%O_2$	16.35	16.88				
$\%CO_2$	4.80	4.20				
V_ESTPD	84.21	88.46				
VO_2	3.825	3.566				
15.						
$\%O_2$	16.20	16.05	16.78			
$\%CO_2$	4.70	4.75	4.85			
V_ESTPD	75.21	78.85	90.43			
VO_2	3.580	3.891	3.603			
16.						
$\%O_2$		15.30	16.05	16.93		
$\%CO_2$		5.40	5.20	4.70		
V_ESTPD		77.65	88.67	116.74		
VO_2		4.436	4.271	4.476		
17.						
$\%O_2$			16.26	16.03	16.53	
$\%CO_2$			4.60	5.30	5.00	
V_ESTPD			95.63	94.60	104.60	
VO_2			4.503	4.555	4.458	
18.						
$\%O_2$			16.98	17.23		
$\%CO_2$			3.70	3.90		
V_ESTPD			109.41	112.72		
VO_2			4.416	4.134		

Subject	5%	7½%	10%	12½%	15%	17½%
19.						
$\%O_2$			16.93	17.53		
$\%CO_2$			4.40	3.80		
V_ESTPD			95.13	103.88		
VO_2			3.725	3.444		
20.						
$\%O_2$	16.48	16.46				
$\%CO_2$	4.75	4.90				
V_ESTPD	82.97	85.01				
VO_2	3.644	3.721				
21.						
$\%O_2$		15.08	16.40	16.88	17.45	
$\%CO_2$		5.90	4.00	4.80	4.70	
V_ESTPD		59.72	84.48	108.72	107.71	
VO_2		3.497	3.963	4.209	3.422	
22.						
$\%O_2$	16.75	15.99	16.80			
$\%CO_2$	5.80	5.40	4.70			
V_ESTPD	72.57	83.84	78.95			
VO_2	2.736	4.055	3.158			
23.						
$\%O_2$		16.28	16.03	16.25	16.93	
$\%CO_2$		4.65	4.95	5.15	4.75	
V_ESTPD		82.85	82.02	96.16	109.51	
VO_2		3.869	4.025	4.401	4.186	
24.						
$\%O_2$			16.73	16.98	17.42	
$\%CO_2$			4.65	4.50	4.50	
V_ESTPD			111.56	119.95	114.33	
VO_2			4.575	4.589	3.738	

RAW SCORES OBTAINED ON THE MODIFIED ASTRAND BICYCLE ERGOMETER TEST OF MAXIMAL OXYGEN UPTAKE

Work Level Expressed in Kilopond Meters per Minute

Subject	900	1200	1500	1800	1950	2100
1.						
$\%O_2$	15.88	15.35	15.90	16.63		
$\%CO_2$	4.40	4.80	4.50	4.00		
V_ESTPD	40.51	52.29	78.36	93.62		
VO_2	2.123	3.036	4.069	4.119		
2.						
$\%O_2$	16.28	16.70	16.93	16.95		
$\%CO_2$	4.20	4.00	4.00	3.40		
V_ESTPD	52.71	79.53	99.19	94.97		
VO_2	2.525	3.429	3.988	3.944		
3.						
$\%O_2$	15.98	16.25	17.20	17.51		
$\%CO_2$	4.40	4.40	3.70	3.05		
V_ESTPD	44.06	62.15	100.95	111.75		
VO_2	2.254	2.967	3.794	3.954		
4.						
$\%O_2$	15.48	16.28	16.61	17.73		
$\%CO_2$	4.80	4.30	4.10	2.60		
V_ESTPD	45.80	74.10	91.19	118.44		
VO_2	2.584	3.531	4.011	4.003		
5.						
$\%O_2$	17.04	16.75	17.63	17.58		
$\%CO_2$	3.80	4.20	3.50	3.10		
V_ESTPD	57.13	70.48	107.66	96.01		
VO_2	2.247	2.957	3.517	3.299		
6.						
$\%O_2$	17.95	17.68	17.68	17.70		
$\%CO_2$	3.05	3.20	3.30	2.70		
V_ESTPD	85.52	108.94	131.42	111.51		
VO_2	2.551	3.577	4.280	3.780		
7.						
$\%O_2$	15.76	15.33	15.93	16.80	17.00	
$\%CO_2$	4.80	5.20	4.80	3.75	3.50	
V_ESTPD	47.33	58.31	84.59	107.56	122.64	
VO_2	2.502	3.338	4.292	4.572	4.985	
8.						
$\%O_2$	15.36	15.55	17.06	16.23		
$\%CO_2$	4.60	4.65	3.70	3.40		
V_ESTPD	44.96	69.62	105.99	57.79		
VO_2	2.628	3.895	4.171	2.927		

Subject	900	1200	1500	1800	1950	2100
9.						
$\%O_2$	15.88	16.53	17.50	16.73		
$\%CO_2$	4.55	4.20	3.00	2.85		
V_ESTPD	51.00	83.61	101.35	69.49		
VO_2	2.654	3.740	3.612	3.181		
10.						
$\%O_2$	13.68	13.69	14.80	15.80	15.53	
$\%CO_2$	6.05	5.85	5.80	4.80	4.10	
V_ESTPD	31.10	50.05	68.03	84.52	71.38	
VO_2	2.360	3.819	4.244	4.428	4.115	
11.						
$\%O_2$	15.21	15.13	16.03	16.95		
$\%CO_2$	4.50	4.90	4.60	3.60		
V_ESTPD	36.15	45.18	82.78	99.96		
VO_2	2.193	2.738	4.140	4.099		
12.						
$\%O_2$	15.70	15.98	16.93	17.20		
$\%CO_2$	4.65	4.45	3.80	2.75		
V_ESTPD	46.01	67.92	95.94	81.86		
VO_2	2.486	3.465	3.908	3.284		
13.						
$\%O_2$	14.98	16.06	17.04	16.53		
$\%CO_2$	4.65	4.30	3.65	3.20		
V_ESTPD	32.82	67.12	112.88	80.15		
VO_2	2.073	3.384	4.486	3.798		
14.						
$\%O_2$	17.01	16.58				
$\%CO_2$	3.60	3.30				
V_ESTPD	75.59	61.72				
VO_2	3.042	2.869				
15.						
$\%O_2$	15.75	17.03	17.63	17.05		
$\%CO_2$	4.70	3.70	3.20	3.20		
V_ESTPD	44.83	76.33	101.51	89.19		
VO_2	2.387	3.033	3.398	3.639		
16.						
$\%O_2$	15.78	15.13	16.36	17.10		
$\%CO_2$	4.60	5.00	4.60	3.30		
V_ESTPD	41.94	55.67	93.04	99.79		
VO_2	2.229	3.358	4.263	3.983		
17.						
$\%O_2$	16.01	15.85	16.83	16.74		
$\%CO_2$	4.20	4.60	3.60	3.50		
V_ESTPD	51.38	66.76	109.98	102.64		
VO_2	2.636	3.490	4.677	4.510		

Subject	900	1200	1500	1800	1950	2100
18.						
$\%O_2$	16.65	17.03	17.48	16.93		
$\%CO_2$	3.80	3.45	3.20	2.85		
V_ESTPD	63.08	88.88	116.14	76.71		
VO_2	2.792	3.590	4.108	3.319		
19.						
$\%O_2$	15.75	16.63	16.53	16.29		
$\%CO_2$	4.40	4.00	3.90	3.50		
V_ESTPD	42.68	77.16	78.24	65.11		
VO_2	2.307	3.395	3.561	3.231		
20.						
$\%O_2$	17.53	16.94	15.86			
$\%CO_2$	3.40	3.20	3.50			
V_ESTPD	83.33	69.54	41.50			
VO_2	2.850	2.934	2.286			
21.						
$\%O_2$	15.43	16.13	17.21	17.23		
$\%CO_2$	4.50	4.40	3.05	2.80		
V_ESTPD	43.15	67.97	106.88	82.08		
VO_2	2.497	3.349	4.188	3.250		
22.						
$\%O_2$	15.59	16.33	16.40	16.95		
$\%CO_2$	4.90	4.50	4.30	3.40		
V_ESTPD	46.35	71.39	86.28	85.57		
VO_2	2.538	3.318	3.978	3.555		
23.						
$\%O_2$	14.85	16.14	16.20	16.92		
$\%CO_2$	5.20	4.45	4.20	3.10		
V_ESTPD	37.09	63.88	75.55	70.97		
VO_2	2.349	3.131	3.694	3.031		
24.						
$\%O_2$	15.08	14.68	16.68	16.68	17.38	
$\%CO_2$	5.20	5.55	4.35	3.60	3.00	
V_ESTPD	36.76	48.25	96.54	91.44	72.10	
VO_2	2.221	3.115	4.098	4.063	2.680	

RAW SCORES FROM MODIFIED ASTRAND BICYCLE ERGOMETER TEST OF MAXIMAL OXYGEN UPTAKE FOR SUBSIDIARY PROBLEM

Subject	Work Level Expressed in Kilopond Meters Per Minute					
	900	1200	1500	1800	1950	2100
25.						
$\%O_2$	15.25	15.78	16.35	15.93		
$\%CO_2$	4.70	4.50	3.60	4.00		
V_ESTPD	45.88	62.63	67.76	60.70		
VO_2	2.734	3.347	3.292	3.209		
30.						
$\%O_2$	16.69	16.95	17.20	17.38		
$\%CO_2$	3.90	3.80	3.55	2.90		
V_ESTPD	57.95	70.80	74.29	72.68		
VO_2	2.522	2.867	2.822	2.719		
32.						
$\%O_2$	15.20	16.58	16.60	16.63		
$\%CO_2$	5.15	4.00	3.60	3.00		
V_ESTPD	40.68	71.60	68.30	58.95		
VO_2	2.402	3.195	3.105	2.750		
40.						
$\%O_2$	15.44	15.01	16.75	16.68		
$\%CO_2$	5.10	4.15	3.40	3.65		
V_ESTPD	45.40	71.33	79.12	53.59		
VO_2	2.549	4.576	3.487	2.780		
43.						
$\%O_2$	15.51	16.85	16.70	17.03		
$\%CO_2$	4.70	3.70	3.50	3.00		
V_ESTPD	43.16	76.56	72.45	76.43		
VO_2	2.429	3.217	3.221	3.179		
44.						
$\%O_2$	15.73	16.10	16.80	16.48		
$\%CO_2$	4.70	4.30	3.75	3.00		
V_ESTPD	52.81	72.69	84.63	65.70		
VO_2	2.827	3.627	3.598	3.190		
47.						
$\%O_2$	13.98	13.86	14.55	16.30	16.25	
$\%CO_2$	4.90	5.70	5.60	4.60	3.80	
V_ESTPD	39.87	42.29	65.88	85.99	82.07	
VO_2	2.995	3.151	4.352	4.005	4.050	
49.						
$\%O_2$	16.23	16.84	15.88	16.19		
$\%CO_2$	4.20	3.70	4.30	4.00		
V_ESTPD	62.17	78.18	44.12	53.53		
VO_2	3.016	3.295	2.325	2.654		

Subject	900	1200	1500	1800	1950	2100
51.						
$\%O_2$	14.58	15.08	16.31	16.03	16.53	15.80
$\%CO_2$	5.35	5.10	4.30	3.60	3.10	3.40
$V_E STPD$	37.31	57.22	94.52	79.50	89.70	68.17
VO_2	2.476	3.472	4.466	4.186	4.274	3.824
53.						
$\%O_2$	17.05	17.34	17.00			
$\%CO_2$	3.50	3.15	2.70			
$V_E STPD$	75.04	79.94	70.14			
VO_2	3.003	2.980	3.00			
57.						
$\%O_2$	16.31	16.28	16.43	16.03		
$\%CO_2$	4.20	4.00	3.80	3.50		
$V_E STPD$	53.35	87.53	65.17	51.09		
VO_2	2.535	4.240	3.054	2.703		
62.						
$\%O_2$	17.25	17.25	17.50			
$\%CO_2$	3.50	3.20	2.40			
$V_E STPD$	66.44	66.91	58.11			
VO_2	2.489	2.561	2.164			